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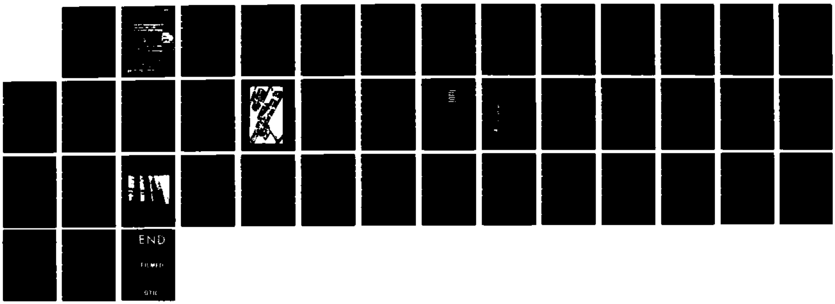

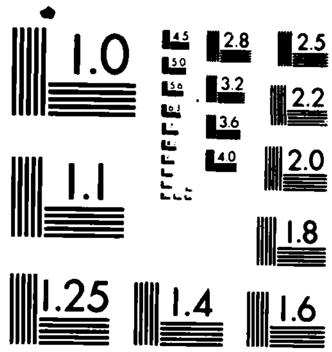

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RECENT IMPROVEMENTS TO THE NAE 5 FT × 5 FT WIND TUNNEL

AMÉLIORATIONS RÉCENTES À LA SOUFFLERIE À RAFALES DE 5 PI × 5 PI DE L'ÉAN

by/par

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SUMMARY

Although the NAE 5 ft × 5 ft Blowdown Wind Tunnel was conceived in the 1950's, with commissioning in 1962/63, it has stood the test of time very well and is still, in 1985, in heavy demand. We may cite three main reasons for this situation: (i) the basic wind tunnel design was fundamentally very sound; (ii) the wind tunnel circuit and its auxiliary systems have frequently been improved and modernized so that it, even today, is a modern up-to-date facility; (iii) the high level of competence of the supporting staff. In this report we present the major improvements made in recent years and the impact these have had on the performance of the facility.

The improvements elaborated on are:

The rebuild of the settling chamber;
The rebuild of the exhaust diffuser;
The installation of active Mach number control for subsonic-transonic operation;
The incorporation of dual drive on the two-dimensional insert balance system;
The suppression of edgetone noise;
The incorporation of highly accurate digital pressure transducers;
The control and data processing system.

Finally, future plans for expanded utilization of the wind tunnel are outlined.

RÉSUMÉ

Même si la soufflerie à rafales de 5 pi × 5 pi de l'ÉAN a été conçue dans les années 1950 et mise en service en 1962-1963, elle a subi l'épreuve du temps avec succès, et elle est encore très en demande en 1985. Ce succès tient à trois principaux facteurs: (i) le modèle de base de la soufflerie était essentiellement très au point; (ii) le circuit et les systèmes auxiliaires de la soufflerie ont été améliorés et modernisés à plusieurs reprises de sorte que l'installation est encore aujourd'hui très actuelle; (iii) le personnel de soutien est très compétent. Le présent rapport décrit les grandes améliorations qui ont été apportées au cours des dernières années et leurs effets sur la qualité de l'installation.

Ces améliorations sont:

La reconstruction de la chambre de tranquilisation
La reconstruction du diffuseur de sortie
L'installation d'une commande active du nombre de Mach pour les essais subsoniques et transsoniques
L'addition d'un entraînement double dans le système d'équilibrage bidimensionnel
L'élimination des bruits de bord
L'addition de transducteurs de pression numériques très précis
Le système de commande et de traitement des données.

Enfin, les plans d'expansion du programme d'utilisation de la soufflerie sont décrits.

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RECENT IMPROVEMENTS TO THE NAE 5 FT × 5 FT BLOWDOWN WIND TUNNEL

1.0 INTRODUCTION

Although the NAE 5 ft × 5 ft Blowdown Wind Tunnel (Fig. 1) was conceived in the 1950's, with commissioning in 1962/63, it has stood the test of time very well and is still, in 1985, in heavy demand. We may cite three main reasons for this situation: (i) the basic wind tunnel design was fundamentally very sound; (ii) the wind tunnel circuit and its auxiliary systems have frequently been improved and modernized so that it, even today, is a modern up-to-date facility; (iii) the high level of competence of the supporting staff.

The wind tunnel, described in fair detail in Reference 1, was designed and built by Canadian companies and is an excellent showcase for Canadian high technology. It has served as prototype for several other similar wind tunnels being built by the same companies in other parts of the world. The design stands out in one respect to other 'contemporary' designs in that the wind tunnel structure is stressed for an internal overpressure (17 bar), that would be generated if a control valve run-away condition occurred. In contrast other designs meet the overpressure situation by incorporating a diaphragm that bursts at, say, 4 or 5 bar. The high pressure capability of the NAE wind tunnel was an important factor for the success of the NAE high Reynolds number two-dimensional test section (Fig. 2), incorporated in 1969 (Ref. 2), that inserts into the transonic test section of the wind tunnel. With the 2-D test section in place it is not uncommon to operate the facility at pressures as high as 10 bar.

The improvements made over the years have in some cases been prompted by failures of original components, in other cases by more stringent demands by the users, and lastly by technological developments and the desire to provide the services of an up-to-date competitive facility.

In the following we shall first discuss the major improvements that have been made in recent years to the basic wind tunnel circuit, that is to the settling chamber and its entrance diffuser, and the subsequent improvements in flow quality and external noise characteristics.

Other important enhancements of the wind tunnel system are then presented; the incorporation of an active Mach number control system, the use of digital pressure transducers for primary wind tunnel pressure measurements, the incorporation of a synchronous dual drive on the two-dimensional balance system and the much expanded control and data processing system.

Finally, future plans for increased utilization of the facility are outlined.

2.0 REFURBISHMENT OF SETTLING CHAMBER AND ENTRANCE DIFFUSER

2.1 Physical Changes

The first major deliberate change to the original wind tunnel circuit took place in 1977, when the inside of the settling chamber and its entrance diffuser was rebuilt. The basic geometry of this area is depicted in Figure 3. This refurbishment was prompted by repeated failures of turbulence damping screens. The causes of these failures were diagnosed to be due to poor edge fixation of the screens and wildly fluctuating flow entering the settling chamber. The latter was of major concern, since new screens would also be subjected to this fluctuating flow, which had peak dynamic pressures an order of magnitude higher than that for uniform flow. The cure was to redesign the two rather open perforated plates and the conical centerbody. The original plates had a porosity of 52% and 54% respectively which was far too open for them to be effective as flow spreaders. The new plates were given a porosity of 41% and 23% respectively. The conical centerbody was changed from a 60° included angle cone to 75° included angle cone.

These modifications have resulted in a significant change in the flow area distribution through the inlet diffuser as shown in Figure 4. The improvements in settling chamber flow resulting from these changes are discussed in Section 2.2 below.

The investigation, on which this replacement scheme was based, was carried out in a 1/12-scale pilot facility and is reported on in Reference 3.

The replacement of the turbulence damping screens was a major undertaking that, apart from the screen material itself, had to be carried out as an in-house operation (Ref. 4). The original screen attachment was of a catenary type, with the screen wrapped around a 1/2″ steel cable, with a thick layer of vulcanized rubber forming an integral part of the screen and cable. Ninety spring supported clamps provide fixation for each screen over the vulcanized cable-screen edge. The original clamps were quite narrow, resulting in about five inches of unsupported edge between clamps, causing significant stress concentration in the screen material at the clamps. In the new design the cable size was increased to 1″ and the clamps widened to yield only about two inches of unsupported edge between clamps. In the installation the screen was pre-tensioned so that the free edge would not buckle under load, resulting in a uniform load distribution around the edge.

The new screen material first ordered was a direct replacement of the original 0.032 inch diameter stainless steel wire with 11 mesh per inch (43.6% porosity). However, the supplier encountered difficulties with the only available loom capable of making the 18 feet wide screens and a concession became necessary. The order was subsequently revised to six 10-mesh screens (46.2% porosity) and one 7-1/2 mesh (57.8% porosity). The reason for the 7-1/2 mesh screen, which was to be the most downstream screen was a belief that this would enhance the uniformity of the free stream turbulence, as evidenced in Reference 5.

An interesting by-product of the in-house screen manufacturing was that the techniques and tools that were developed were later licensed and leased to a Canadian company for screen manufacture, in connection with the sale of a Canadian wind tunnel abroad: a perfect example of technology transfer from an NRC laboratory to industry.

A direct measure of the success of the combined effect of the new screen design and the improvements made to the inlet diffuser can be found in the following facts: in the original tunnel circuit the screens failed at an average rate of one per 4,630 blowdowns. In the rebuilt version the screens have to date (April 1985) been exposed to nearly 9,000 blowdowns with no failure or sign of deterioration.

2.2 Improvement in Flow Quality

2.2.1 Settling Chamber Flow

To verify the anticipated improvement in flow quality resulting from the changes described in the preceding section, measurements were performed of the dynamic pressure variations at the downstream end of the acoustic baffles (See Fig. 3). Because of the much increased load on the perforated plates, particularly the downstream one, it was also deemed important to perform measurements of hoop and longitudinal stresses in the pressure shell of the entrance diffuser. These latter measurements showed that the peaks of the unsteady stresses were so sharply reduced that, even though the steady stress level rose on account of the much higher pressure drop, the instantaneous peaks of total stress were lower than before the changes. Figure 5 illustrates this lowering of peak stresses, a direct consequence of the reduction in pressure fluctuations.

The sample results shown in Figure 6 demonstrate that after rebuild the variation of dynamic pressure in the central baffle space was much reduced as was the general level. Also a relatively higher proportion of the flow was noted at the larger radii than before the rebuild. This effect follows from the much reduced porosity of the spherical baffle plates and the increased angle of the conical centre body which also acts as a flow spreader.

2.2.2 Test Section Flow

There is only one case for which a direct comparison can be made of the test section flow quality, with the settling chamber in its original (all 7 screens intact) and its refurbished configurations. At a Mach number of 0.8 and a stagnation pressure of 3 Bar centerline noise measurements were made in the early 1960's using a 1/4" B & K microphone. The measurements were repeated under the same mean flow conditions in 1979 using a high frequency response Kulite pressure transducer mounted near the apex of a 10° cone. In both cases the pressure sensor measured the fluctuations in static pressure (underneath a laminar boundary layer). The results are depicted in Figure 7. The lower graph shows the $C_{p_{rms}}$ level versus Mach number for both the subsonic (solid walls) and transonic (perforated walls) test sections for the wind tunnel in its present condition. Also shown are the two data points (pts 1 & 3) obtained in the early 1960's, with the settling chamber in its original configuration. The improvement in flow quality, as portrayed by the $C_{p_{rms}}$ level, due to the rebuild of the settling chamber, is quite dramatic. This improvement is primarily a result of the changes made in the settling chamber inlet diffuser. The power spectra in the upper graph of Figure 7 show, not surprisingly, that the spectral content is quite different from the 'old' and 'new' conditions. Note that the spectra are drawn to the same scale, but the level is arbitrary. Comparing the subsonic test section cases, curves 3 & 4, we may speculate that curve 3 represents primarily control valve generated noise, that is effectively suppressed by the new, much more restrictive, perforated plates in the inlet diffuser, curve 4. The same argument can be had for the transonic test section cases, curves 1 and 2, but there the spectra are modulated by the presence of edgetones from the perforated walls.

Prior to the rebuild of the settling chamber (with only three of the original seven turbulence damping screens in place) stagnation pressure and flow angle surveys were carried out in the test section. The surveys were repeated under identical nominal flow conditions (Mach number and stagnation pressure) after the refurbishment, described in Section 2.1.

The stagnation pressure surveys were effected by means of a rake of rapid response pitot tubes (on 6 inch centres) that was mounted at mid height and spanning the test section. Typical results, for a Mach number of 0.5 and a stagnation pressure of 45 psia, are shown in Figure 8. There is a significant decrease in the pressure fluctuations across the entire width of the test section as a result of the rebuild, with the most dramatic changes occurring near the tunnel walls (18" and 24" from centre-line). Similar improvements were also obtained at other flow conditions.

The flow angle surveys were carried out with four-hole fast response yawmeters at the same position as the pitot tubes. The sample results presented in Figure 9, for a Mach number of 0.9 and a stagnation pressure of 31 psia, show an order of magnitude reduction in the flow angle fluctuations as a result of the rebuild. It may be inferred that the flow angle fluctuations are in part a manifestation of the stagnation pressure fluctuations.

Finally in Figure 10, the overall noise level for various major transonic wind tunnels are depicted. The figure is drawn from Reference 6, but with the NAE data highlighted.

We see that the NAE 5 ft X 5 ft wind tunnel compares favourably with even closed circuit wind tunnels. It should be noted that the data shown in Figure 10, apart from the NAE data, are from the 1970's and that some of the wind tunnels may have undergone improvements since then.

3.0 REFURBISHMENT OF EXHAUST DIFFUSER

3.1 Installation of Flow Spreaders and Silencer

Following the destruction of the original silencer in 1970 during a high mass flow run, the tunnel was operated without silencing for a number of years. This was possible without an adverse reaction from the community because the wind tunnel is sited at the airport (and military base) which is a high noise area. Also very little evening and no night-time operation of the wind tunnel has

occurred. However, this situation will not continue indefinitely and in 1982 a decision was made to replace the silencer.

The restoration of the silencer to the exhaust duct also entailed the rebuilding of two forms of 'catchnet' (as they were originally termed — now referred to as flow spreaders). The function of these is to give some protection to the silencer modules by spreading the flow which is naturally concentrated in the middle of the duct following the terminal shock wave system that inevitably separates the flow already in the upstream shallow angle diffuser.

The flow spreaders have been built from I-section beams to form square grids — one is fixed about halfway along the wide angle diffuser and a second at the exit as indicated in Figure 11. The geometric area blockage provided by the flow spreaders is 36% and 40% for the upstream and downstream one respectively. The flow spreaders are entirely an in-house design. They were installed by a local contractor in February, 1984.

The silencer was designed and built by Vibron, a Canadian company located in Mississauga, Ontario, to NAE specification. It is a parallel baffle type with thirteen modules, each 10 ft long, 27 ft high and 1 ft wide (See Figure 12). The modules are made of perforated galvanized steel and packed with sound absorbing material to a density of 5 lb/ft^3. The silencer was installed by Vibron in July, 1984.

3.2 Flow and Noise Characteristics

The effectiveness of the I-beam construction as a flow-spreader device had been studied in the NAE 5 in X 5 in pilot wind tunnel (a 1/12-scale model of the 5 ft X 5 ft wind tunnel) before deciding on the present design. However it was deemed important and of interest to also establish its effectiveness in full scale. To that effect the distribution of stagnation pressure was measured along a horizontal line at mid height at the location of the upstream flow spreader both before and after erection of the structure. Figure 13 shows pitot tubes mounted on the upstream flow spreader — for the empty diffuser measurements the same tubes were mounted on a separate support spanning the diffuser. The tubes were equipped with 25 psid pressure transducers, referenced to atmospheric pressures, in their bases. The frequency response of the system was flat up to 400 Hz. Hence, a good representation of unsteady as well as the steady components of the stagnation pressure could be obtained.

Sample results are presented in Figure 14 — these demonstrate a redistribution of the flow towards the outer region due to the resistance generated by the flow spreaders and also a small but measurable reduction in the unsteadiness part of the stagnation pressure. This latter observation is believed to be due to the increase in back pressure brought on by the presence of the flow spreaders, resulting in upstream movement and weakening of the terminal shock system in the shallow angle diffuser with consequently less severe flow separation. Note that these measurements were made before the silencer was installed.

The effectiveness of the silencer was established for the qualifying case: 2-D test section, Mach No. = 0.725, stagnation pressure 106 PSIA yielding a mass flow of 2750 lbs/sec and wintry outdoor conditions. Microphone measurements were performed at a point 150 ft from the exhaust stack. The achieved noise reduction performance is presented in Figure 15, which shows the frequency spectra on the A-weighted scale. The overall noise reduction is 25 dBA — the silencer performed close to predictions.

4.0 MACH NUMBER CONTROL SYSTEM

We shall here discuss the systems developed for the setting and control of Mach number at subsonic and transonic speeds.

At subsonic speed, with the upstream flexible nozzle set parallel, the test section Mach number is controlled by the ratio of the diffuser second throat area to the test section area. This system of control is effective up to a Mach number of about 0.97 with the transonic test section in line. Above this Mach number and up to about 1.4 the Mach number is controlled by regulating the flow from the transonic plenum chamber into the diffuser with the diffuser re-entry flaps, in combination with presetting the upstream flexible nozzle and the slope of the top and bottom walls of the test section. For two-dimensional testing only the first system of Mach number control is used.

4.1 Second Throat Choke Control

In the original design of the wind tunnel it was envisaged that the diffuser second throat could be actively engaged for Mach number control during wind-on conditions. However, an analysis of the hydraulic actuator system as built, operating on the second throat, showed it to be impractical to operate under wind-on conditions. Another form of second throat control was therefore required.

A translating choke system was favourably considered and such a system was installed in late 1983. The system consists of two vertically translating chokes protruding through the centre of the floor and ceiling respectively at the second throat, Figure 16. The chokes are 8 inches wide and have a total traverse of 30 inches. Their translation is effected by a servo-controlled hydraulic circuit responding to commands from a specially built Mach number controller (microprocessor). The input to the controller is derived from the measured free stream static (plenum) pressure and stagnation pressure via another microprocessor which performs on-line conditioning of the pressure signals, Figure 17.

The control system effects the operation of the chokes so that a requested Mach number is obtained at the beginning of a run and then maintained constant during the course of the run, with the movements of the chokes compensating for varying model blockage effects. The maximum traversing speed of the chokes is 10″ per second. It is also possible to perform a Mach number sweep, for instance from 0.8 to 0.95, with the model at fixed incidence. Figure 18 depicts the performance of the choke system in terms of the Mach number excursion it can cover for both 3-D and 2-D operations. Another feature that applies to 2-D operations is that the system can also be modulated to compensate for wall interference effects on the free stream Mach number. This is done via a special computer algorithm that uses as input the measured pressure difference between two opposing points on the top and bottom walls. Thus for 2-D tests the free stream Mach number, corrected for wall interference, can be held constant during an incidence program. The accuracy to which Mach numbers can be set and maintained constant is generally within ± 0.002, under favourable conditions within ± 0.001.

4.2 Diffuser Re-Entry Flap Control

This system of Mach number control has been available since the wind tunnel was built. However, up till recently, it has only been used for presetting the free stream Mach number. With the advent of the choke system just described, the re-entry flap system was overhauled and its operation incorporated with the Mach number controller in the same way as the choke control previously described. As mentioned above, the flap control can be used up to a Mach number of about 1.4. For the flaps to be effective above $M = 1.15$ the upstream flexible nozzle contour must be changed to a supersonic contour. Nozzle contours are established for discrete Mach numbers only, 1.1, 1.2, 1.3, 1.4 etc. and the effectiveness of the re-entry flaps decreases as the Mach number increases. Figure 19 shows the Mach number excursions that can be accommodated by the re-entry flaps for various nozzle settings and slopes of the top and bottom test section walls. (The rather limited excursions indicated for $M = 1.1$ and 1.2 nozzle settings are a reflection of the limitation of current calibration data.) It should be noted that significant model blockage effects due to incidence change are observed up to a Mach number of 1.2 and that re-entry flap control is therefore essential for maintaining constant Mach number.

Furthermore, the Mach number controller permits 'overlap' between choke and flap control which is essential close to M = 1. This feature makes it possible to perform a Mach number sweep from, say M = 0.95 to M = 1.10, a very important regime in transonic testing. The accuracy of the re-entry flap control system is comparable to, or better than, that of the choke control.

5.0 2-D TEST SECTION IMPROVEMENTS

5.1 2-D Balance Dual Drive

In the original design, models in the 15-inch 2-D test section were driven from one end of the model, with the other end free to rotate with (almost) zero moment. This was done to ensure a non-redundant support system, avoiding the calibration and operational problems of overdetermined structural support systems.

However, some models mounted on the balance were observed to twist significantly — in some cases over 1 degree. Various techniques were devised to correct for twist, using separate incidence measurements on both sides to compute the incidence at tunnel centerline, and resolving force vectors in a common axis system. The assumption in these corrections was that the twist (and therefore the effects of twist) were small, and did not significantly detract from the 2-D nature of the test body. Also, since all the moment was carried by one of the balances, the allowable moment was only half of what could be carried had moment loads been shared. Not all models were vulnerable to this problem. Stiff (thick) models or those with an elastic center near the center of pressure and near the balance centerline were less vulnerable than thin ones or those that were made of many elements (flaps, cover plates, etc.).

The advent of some tests involving particularly thin (4% and 6%) sections and some complex high-lift multi-element airfoils prompted an evaluation of possibilities for circumventing these problems. It was decided that the most promising solution was to drive the model support from both sides. Much of the support system was identical on both sides anyway, so that the addition of another gearbox was a simple addition.

The revised mechanical arrangement, shown in Figure 20, involves a modified drive train; a three-stage worm reduction gear (903.30 : 93.44 : 9.67 : 1.0) driven by large DC servo motors. The motors are equipped with brakes and optical motion detectors which are used by a controller to maintain synchronous movement on the two sides. With this new system the differential angle between the two sides can be kept below 0.05°. Provision is made for various modes of operation and for differential motion of the two sides to minimize moment output due to misalignment of model mounting holes. Incidence is measured with potentiometers mounted on the non-powered end of the last stage of the drive reduction, with a total measuring range of 120 degrees. In the redesign process, improved response (and thus improved tracking) was achieved.

While the basic problem of twist is now resolved, there is one drawback: we now have a redundant model support system/balance, which complicates calibration. This dilemma was resolved by devising a calibration rig that emulates the old non-redundant support, so that the various elements can be calibrated independently, followed by a calibration of the combined redundant support system. As a result the performance of the balance is virtually unchanged from that of the single drive balance system.

5.2 Edgetone Noise Suppression

A significant contribution to the overall noise level in a perforated wall transonic wind tunnel comes from the edgetones generated by the perforations, as demonstrated by the results shown in Figure 7 for the full 5 ft × 5 ft test section. A simple means of suppressing the edgetone noise is to cover the perforations with a fine mesh screen, as demonstrated by Vaucheret, Reference 7. For the full three-dimensional test section such a method would be rather impractical, but for the 2-D test section, where only the narrow (15 inches) floor and ceiling are perforated, the method is

very attractive. Such a scheme is, since 1981, incorporated in the test section, Reference 8. The floor and ceiling are covered with a stainless steel gauze 30 mesh, 0.012" wire, 40.8% open, see Figure 2. The results presented in Figure 21 show the overall noise level in terms of $C_{p_{rms}}$, obtained through pressure measurements using a wall-mounted transducer as indicated in Figure 2. Also shown in Figure 21 are two power spectra curves. The effectiveness of the screens in suppressing the edgetones is clearly evident. Rather interestingly, the presence of the screens has virtually no effect on the wall interference characteristics, in spite of the fact that they reduce the geometric porosity from 20.5% to 8.4%.

The effect of edgetone suppression on aerodynamic measurements, apart from a general improvement in data quality, is surprisingly small and has only been demonstrated at supercritical flow conditions, where a slight downstream movement of the shock wave has been noted, Reference 8.

6.0 CONTROL AND DATA PROCESSING SYSTEM

Data acquisition and wind tunnel control systems have been in a continuous state of development since the Honeywell DDP-516 based data acquisition system, installed in 1971, was in 1978 replaced with a system designed around the Digital Equipment Corp. PDP11/55 computer. Originally it had been intended that several dedicated computers would be used for diverse functions and tied together through a central 'master', but the lack of funds forced a consolidation of all functions into one computer. This has been, in some ways a fortunate thing. Since all data is passed through the same processor, there is no need to co-ordinate and transfer data that might be acquired in one location and needed in another. On the other hand, considerable work was required to develop peripheral attachments that would relieve the workload on the computer to guarantee high throughputs without conflict in the various real-time tasks.

Figure 22 is an overall view of the major components of the system at the present time. All external devices are regarded as peripherals of the PDP11/55 computer, accessed through two types of standard controller cards: 'dumb' and 'micro-processor'. All tunnel testing activities in the laboratory have become dependent on this process: calibrations (amplifiers, transducers, balances, etc.) tunnel operation, data acquisition, data processing, equipment development, model checkout and test preparation procedures have all come to depend heavily on this one machine. At first blush, this may seem like 'putting all the eggs in one basket' but on reflection, risk levels are reduced, since there is only one system to fail. Reliability is more easily achieved through duplication of some of the more vulnerable components, and keeping the number of critical processors required at a minimum.

Recently we have been implementing a 'building block' approach to the design of controllers. Using LSI 11/73 micro-processors, a flexible, standardized means has been available to implement complex, non-linear controllers. These 'smart' controllers sit on a common bus that, in addition to feeding data to the data bus (where it is available to the data acquisition system) permits other micro-controllers to read the data without special communications protocols. In addition, there is a link from these controllers to the data bus, so that controller information is available as normal data channels. In this way, such data as 'q', 'M' and 'Re' can be taken in the same manner as the analogue data. If there should be a failure in one of these controllers, a simple substitution of the processor and down-loading of software gets the facility running very quickly. Repairs are then done (if at all) off-line. All data still flows through the main processor.

The power, flexibility and low cost of this approach indicate that most new controllers in this system will be of a 'microprocessor' type. At this point, model attitude, Mach number and prime pressure measurement systems are implemented through use of these controllers.

In support of this hardware, several interacting real-time tasks were developed to co-ordinate such things as overall logical control of the run (LOGIC) provision of analogue references (REFER) for servo-driven controllers and acquisition of data (DGS). Translators were written to interpret 'English-like' instruction lists into the required tables for the real-time tasks. With the provision of servo references through the task REFER, such variables as stagnation pressure or Mach number can

be varied during a run in the same fashion as such things as model attitude or probe positions. The design of the hardware and software components is such that several independent data acquisition operations can be carried out simultaneously, which makes possible the attachment of auxiliary activities such as calibration or other testing on the same system. This in turn ensures that all support software (plotting, monitoring, etc.) is available to all activities.

The ever increasing number of preparatory functions and auxiliary data acquisition processes have severely taxed the ability of the PDP 11/55 computer, making even limited data processing in that system difficult. Therefore a new VAX 11/785 computer has recently been added to take over the on-line (post-run) data processing and presentation. Magnetic tapes of 800, 1600 and 6250 bpi can be handled, larger memory enables better turn-around and high speed permits more extensive on-line analysis, including wall interference corrections.

7.0 USE OF DIGITAL PRESSURE TRANSDUCERS

For some time, the deteriorating performance of the 20-year old electro-magnetic type primary pressure transducers has been of concern. Hysteresis and repeatability were simply not as good as the original specifications, which were not up to modern standards in any case. Since pressures are fundamental to every measurement made in a wind tunnel, various alternatives were considered for replacement. As discussed above, a new data system with microprocessor controller interfacing became available, and it was decided that a new pressure measuring system would be a logical candidate for upgrading, using new transducers and new techniques. Such a system would provide for easy direct access of pressures through the normal data channels, on-line linearizing of transducer outputs and provision for common calibration constants.

Several possibilities were considered for upgrading, all of which had performance specifications about an order of magnitude better than the 0.03% accuracy and 0.01% zero drift per degree Fahrenheit of the old transducer, and which were considerably faster than the 0.2 second response to within 99.9% of final output for a step pressure input. The finally selected transducer is a quartz crystal oscillator, with a nominal frequency of about 40 kHz, which drops about 10% at full scale pressure application. The transducer is fundamentally a nonlinear device, but through a microprocessor linearization process is made to appear linear to the data system.

It was very early decided that up to 32 channels should be catered for, and that in order to be able to utilize the 23-bit equivalent resolution (able to discern 0.002 psi in 200-psia full-scale) of the transducer, a double-precision (32-bit) recording scheme would be required. In order to achieve maximum stability, the transducer is mounted on a temperature controlled base, thermally isolated from the pressure vessel and with a self-contained battery backup to keep the quartz crystal powered at all times. A section of the installation is shown in Figure 23. The interior cavity is filled with foam insulation and pressure connections for each unit are tuned for optimum response.

The overall system can have up to 32 units, each of which is connected to a microprocessor controller that converts the time for 512 cycles of the 40 kHz signal from the transducer (as referenced against a 100 MHz crystal) into pressure readings using appropriate 2nd order calibration coefficients. The readings are made available in both floating point form (for use by other smart controllers) and integer form (for compatibility with other data). Digital filtering (at both 10 and 3 Hz) is performed on-line, and any desired result is available as required. All of this is updated 50 times per second. Figure 24 shows a schematic of the essential processes involved. Each application has its own dedicated transducer unit, which is simply selected by listing the appropriate channel number in the Master Data used to control the run. All units are in place at all times, and kept powered 24 hours per day, to avoid startup transients and zero shifts. The battery backup is able to keep the crystal excited for up to 3 days.

An interesting problem arose when it came time to calibrate these units: it was necessary to improve our techniques with the dead weight tester. Our first attempts at calibration, while suitable for the older units, were woefully inadequate. However, after improving our methodology there, we were able to get results similar to those shown in Figure 25. There are still some evident small anomalies, but these are insignificant when compared to the 0.125 psi accuracy specification of the old system. It is also interesting to note on that chart that at a given pressure, repeat loadings give extremely reproduceable results, indicating that even better calibrations would be possible if improved use of the dead-weight tester could be arranged.

It is impressive to reflect on how standards have changed over recent years. Such systems as this one demonstrate that measurements can be made to an accuracy an order of magnitude better than the calibration standards of a generation ago.

8.0 FUTURE PLANS

Over the past fifteen or so years the NAE 5 ft X 5 ft wind tunnel has been in very heavy demand by the aerospace industry and research agencies with typically one year or more advance booking. Projections are that this kind of demand will continue for a good many years.

In order for NAE to significantly increase the efficiency and utilization of this wind tunnel so as to better serve the aerospace community, the National Research Council of Canada, the governing body of NAE, has authorized the implementation of a program to expand the operation of the wind tunnel. The program has two basic elements:

(i) to increase the operating hours from the current 5-day, 37.5-hour week to a 5-day, 50-hour week, to be implemented in late 1985.

(ii) to rebuild the transonic test section to facilitate change over from/to various modes of operation; the incorporation of the 'Roll-in, Roll-out' concept. Completion expected in 1987.

The major impact of the first element will be that the number of hours per year available to industry can be increased by nearly 60% over current utilization. The incorporation of the second element will increase this to 70%. More compelling reasons behind the second element are discussed below.

Although the wind tunnel has the capability of operating up to a Mach number of $M = 4.25$, its main use is in the subsonic-transonic speed regime using the transonic test section. This test section can be operated in various modes: two-dimensional, reflection plane (half-model) and fully three-dimensional. The mode change from 3-D to 2-D and vice versa is quite time-consuming, resulting in considerable loss (about 5 weeks) of available productive time. Such a mode change takes place at least once a year.

To facilitate these mode changes and reduce the down time associated with them, the Roll-in Roll-out test section concept has been devised. Its incorporation involves the following:

1. The removal of the existing perforated walls from the transonic test section and preparation of the plenum chamber to accept new test section modules;

2. The construction of a 2-D and a 3-D test section module with new ventilated walls;

3. The construction of a transporter for moving a test section module from its parked position to plenum or vice versa;

4. The construction of an annex adjacent to the wind tunnel bay to provide dedicated parking space for the test section modules.

Figure 26 gives an artist's impression of the new concept.

The enhancements of the 5 ft wind tunnel facility and its operation that will follow from the incorporation of the roll-in roll-out test section concept are manifold:

1. Reduce to a fraction the downtime of the W/T due to change of test section configuration (2-D, 3-D, 1/2 model) or, in other words, substantially increase the effective utilization and potential revenues of the facility;

2. Allow preparatory work in one test section to be carried out while the other is in use;

3. Allow NAE to quickly respond to 'emergency demands' when e.g. a customer has an urgent need for a 3D test during a period set aside for 2D testing;

4. Provide a test section wall configuration that is more in line with the times than the present one, conceived some 25 years ago;

5. Allow NAE to consider and implement new test section configurations through a third module without discarding the 'old' one (no need to burn any bridge prematurely). This last point is crucial since it would provide NAE with virtually unlimited and at present unparalleled opportunities for facility modernization to remain up-to-date and competitive indefinitely.

A preliminary engineering design study, performed by DSMA International Inc., Toronto, has confirmed the soundness and viability of this concept.

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FIG. 1: CUT-AWAY VIEW OF NAE 5 FT × 5 FT WIND TUNNEL

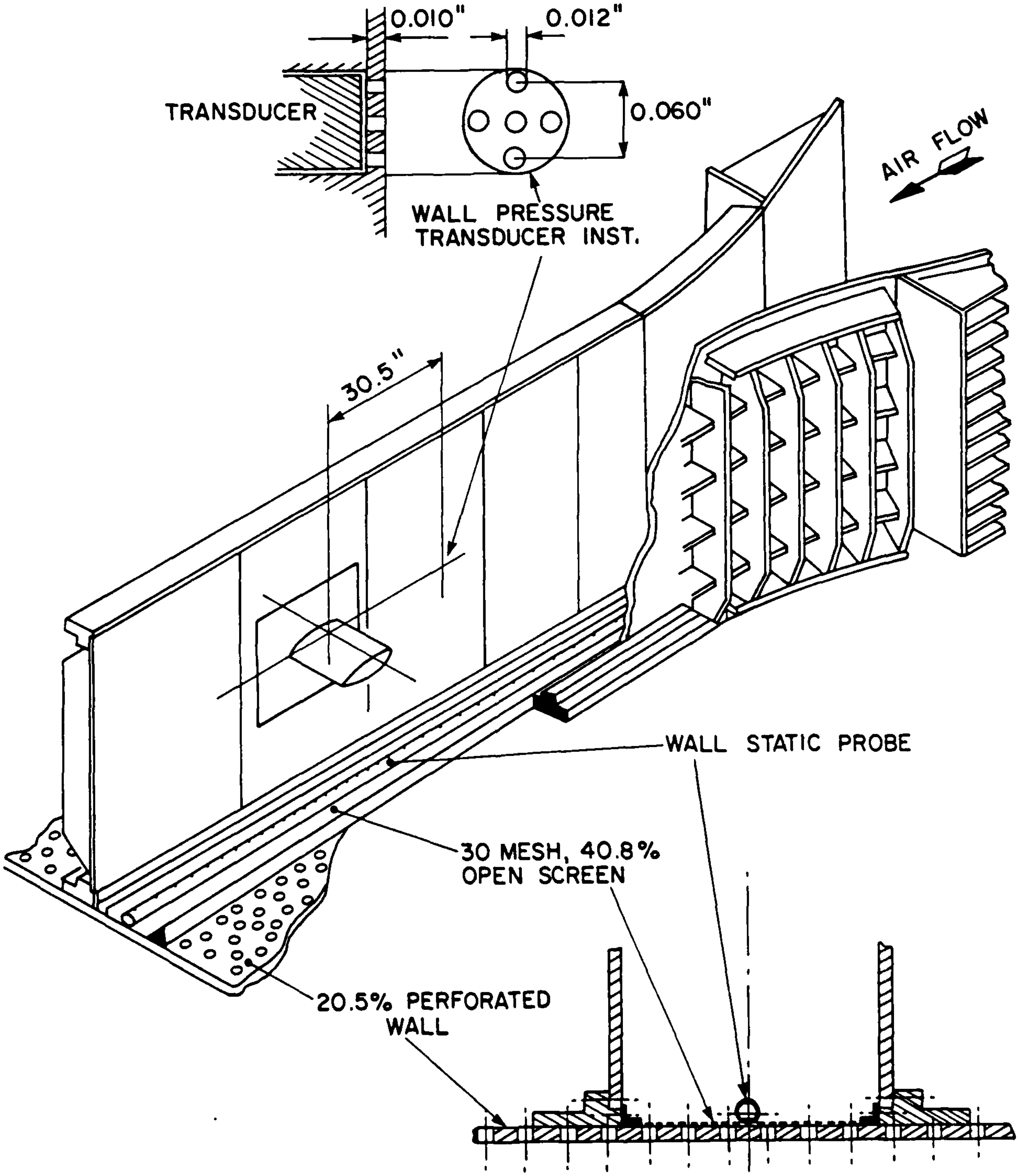


FIG. 2: NAE HIGH REYNOLDS NUMBER TWO-DIMENSIONAL TEST SECTION

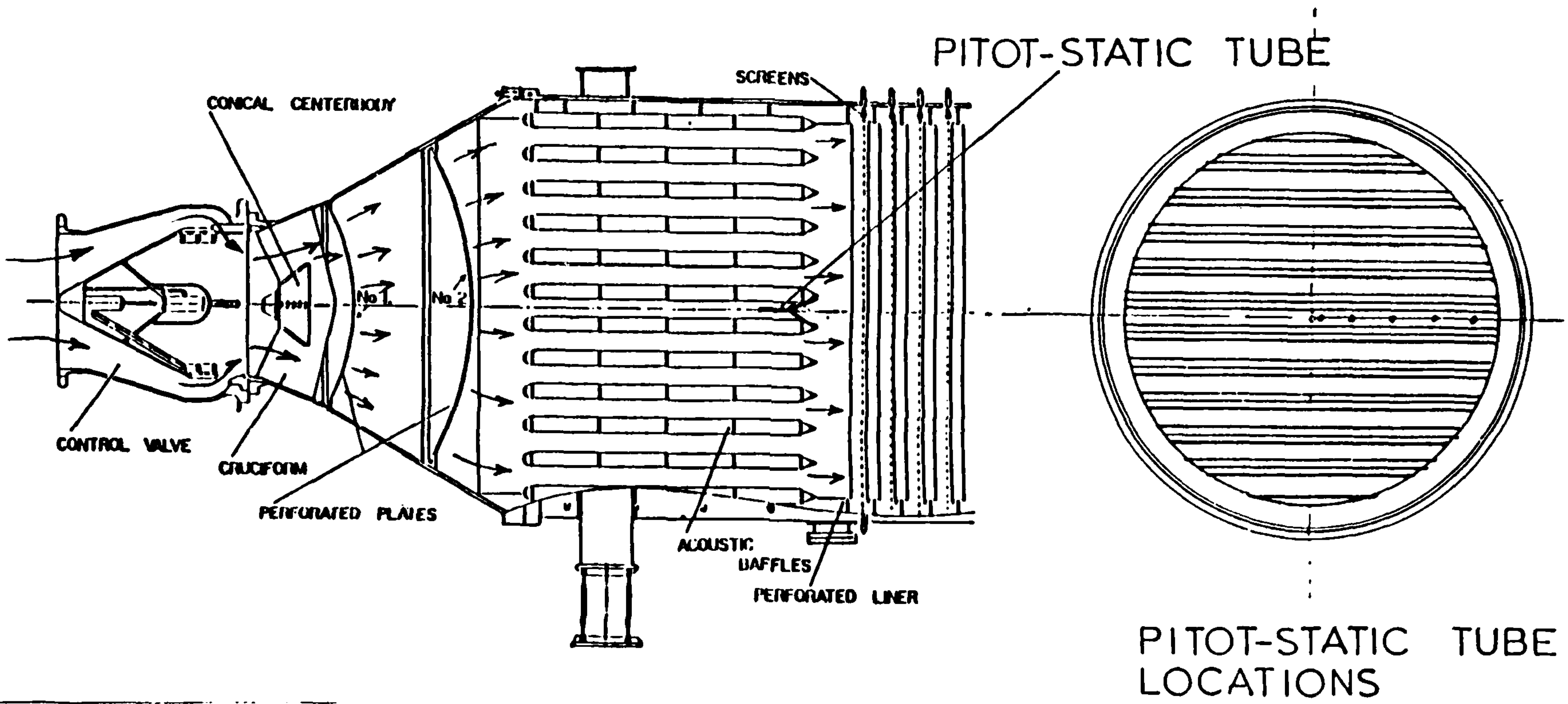


FIG. 3: INLET DIFFUSER-SETTLING CHAMBER GEOMETRY

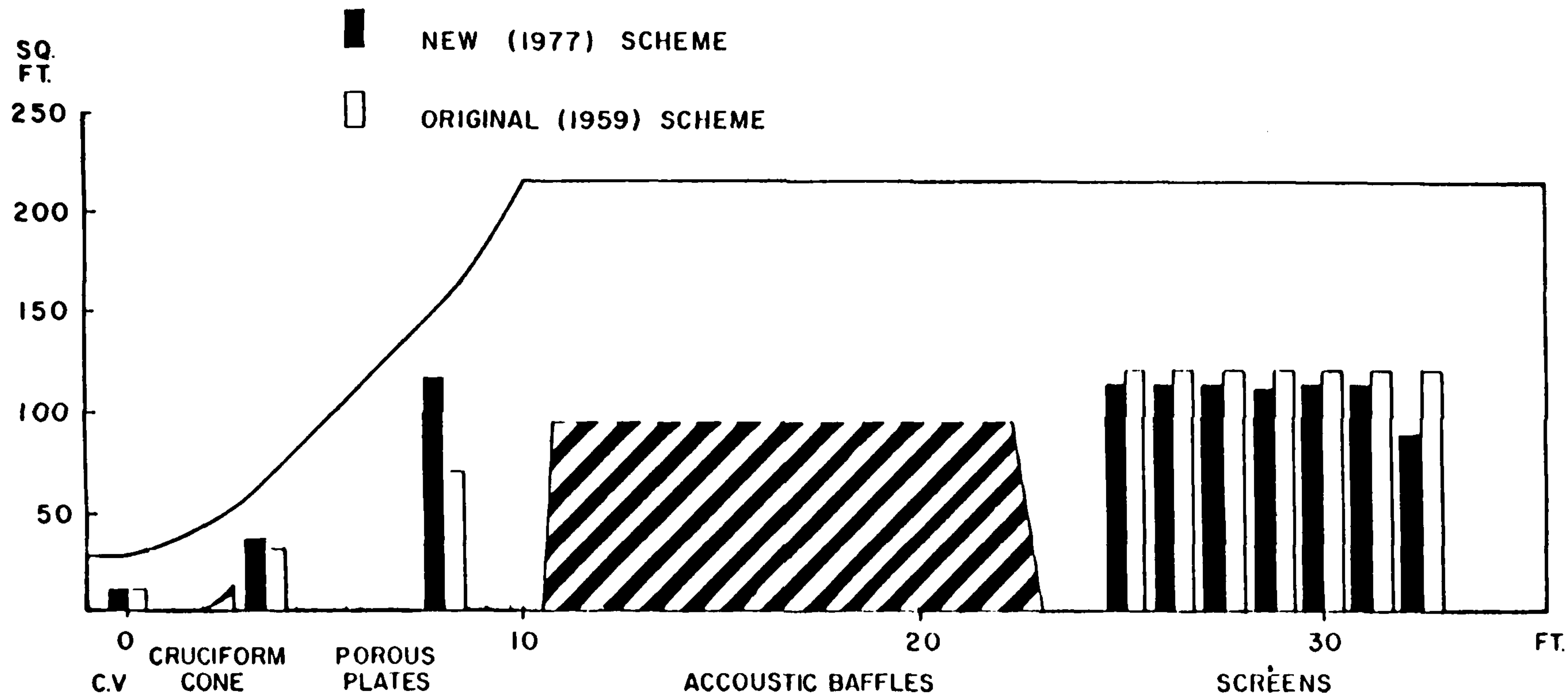


FIG. 4: AREA DISTRIBUTION AND BLOCKAGE OF INLET DIFFUSER-SETTLING CHAMBER

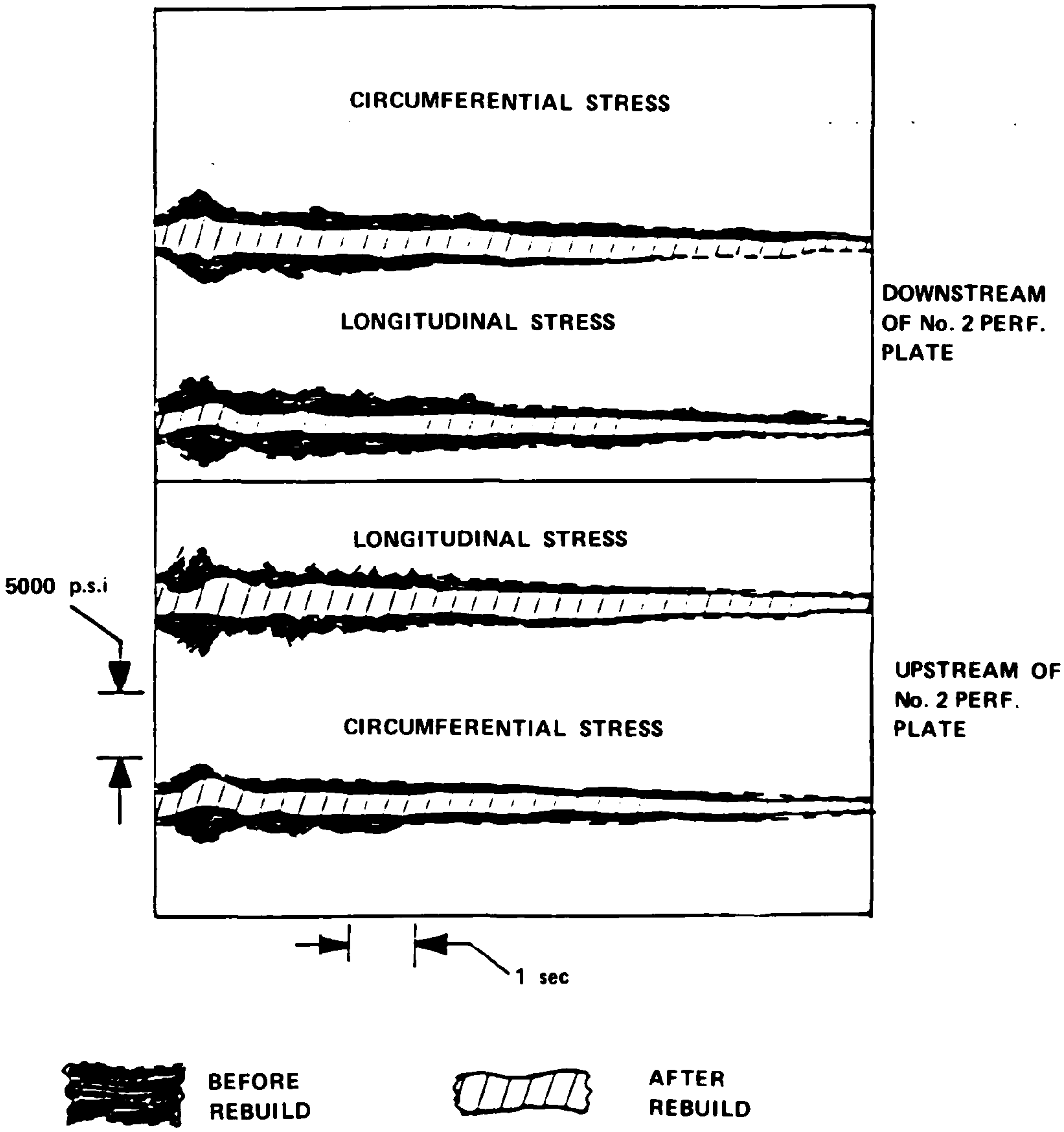


FIG. 5: INLET DIFFUSER SHELL FLUCTUATING STRESSES

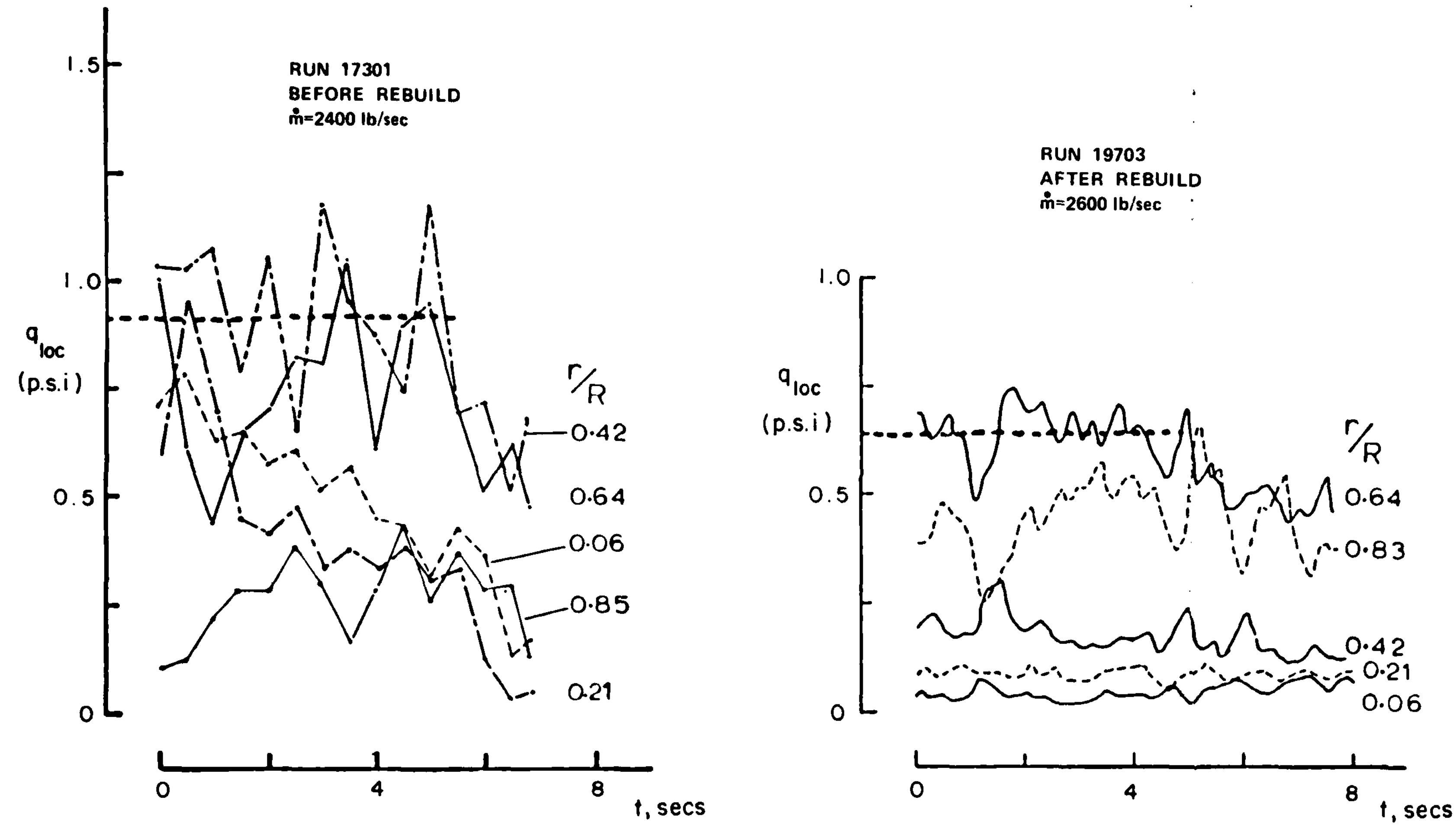


FIG. 6: SETTLING CHAMBER DYNAMIC PRESSURE DISTRIBUTION BEFORE AND AFTER REBUILD

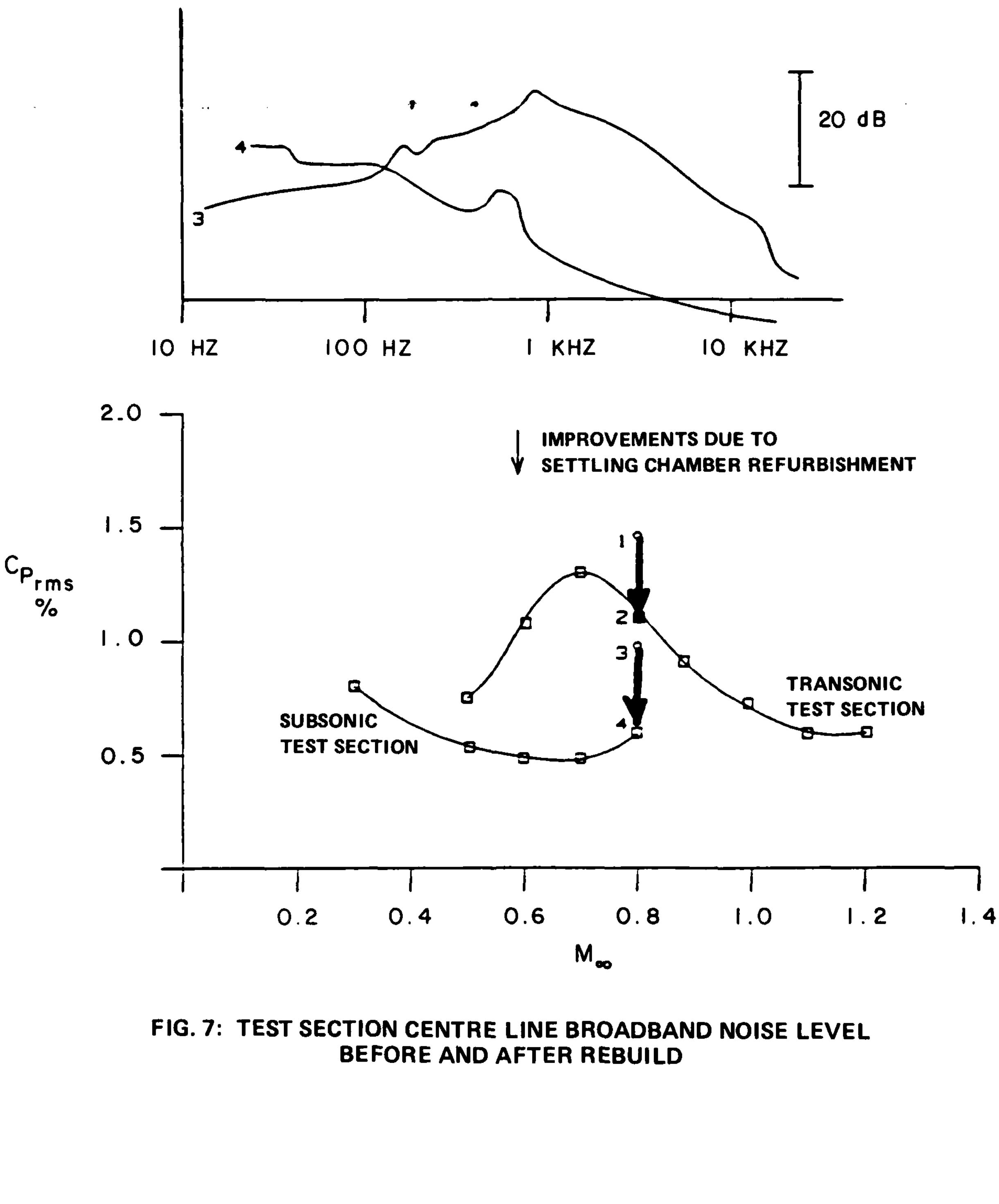


FIG. 7: TEST SECTION CENTRE LINE BROADBAND NOISE LEVEL BEFORE AND AFTER REBUILD

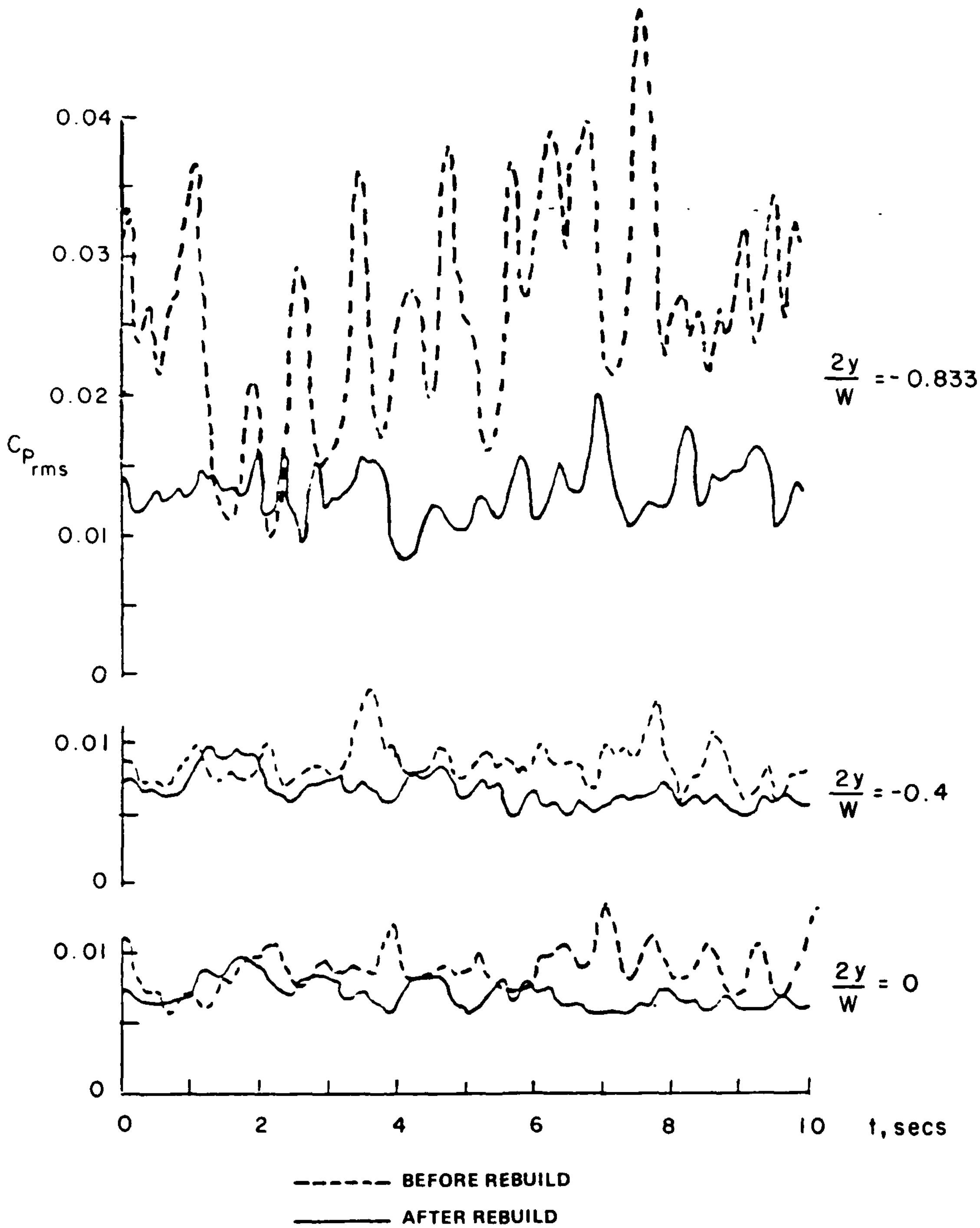


FIG. 8: TEST SECTION STAGNATION PRESSURE $C_{P_{rms}}$ IMMEDIATELY BEFORE AND AFTER REBUILD

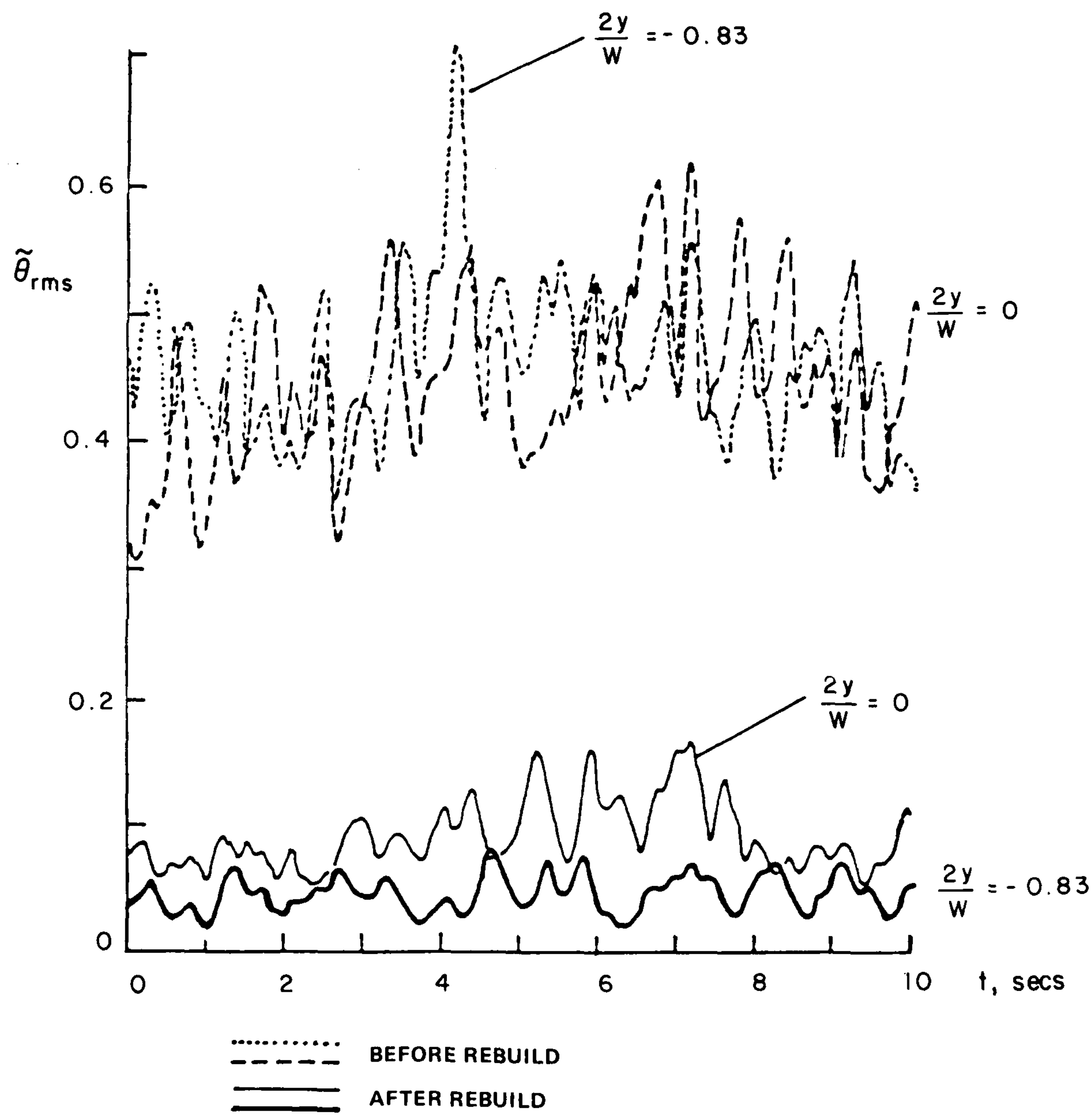


FIG. 9: TEST SECTION FLOW ANGLE FLUCTUATIONS IMMEDIATELY BEFORE AND AFTER REBUILD

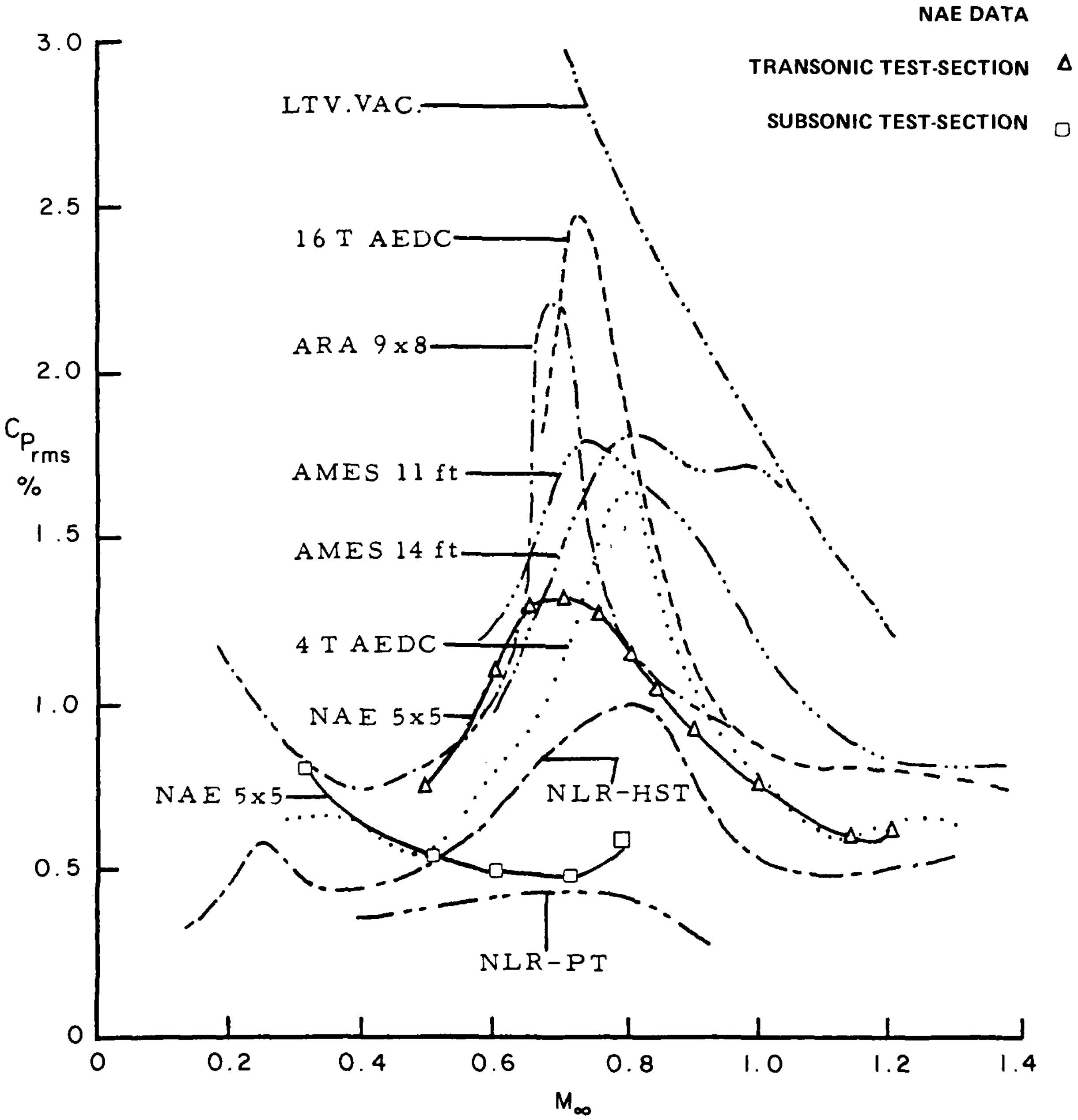


FIG. 10: COMPARISON OF TEST SECTION CENTER LINE BROADBAND NOISE LEVEL FOR TRANSONIC WIND TUNNELS

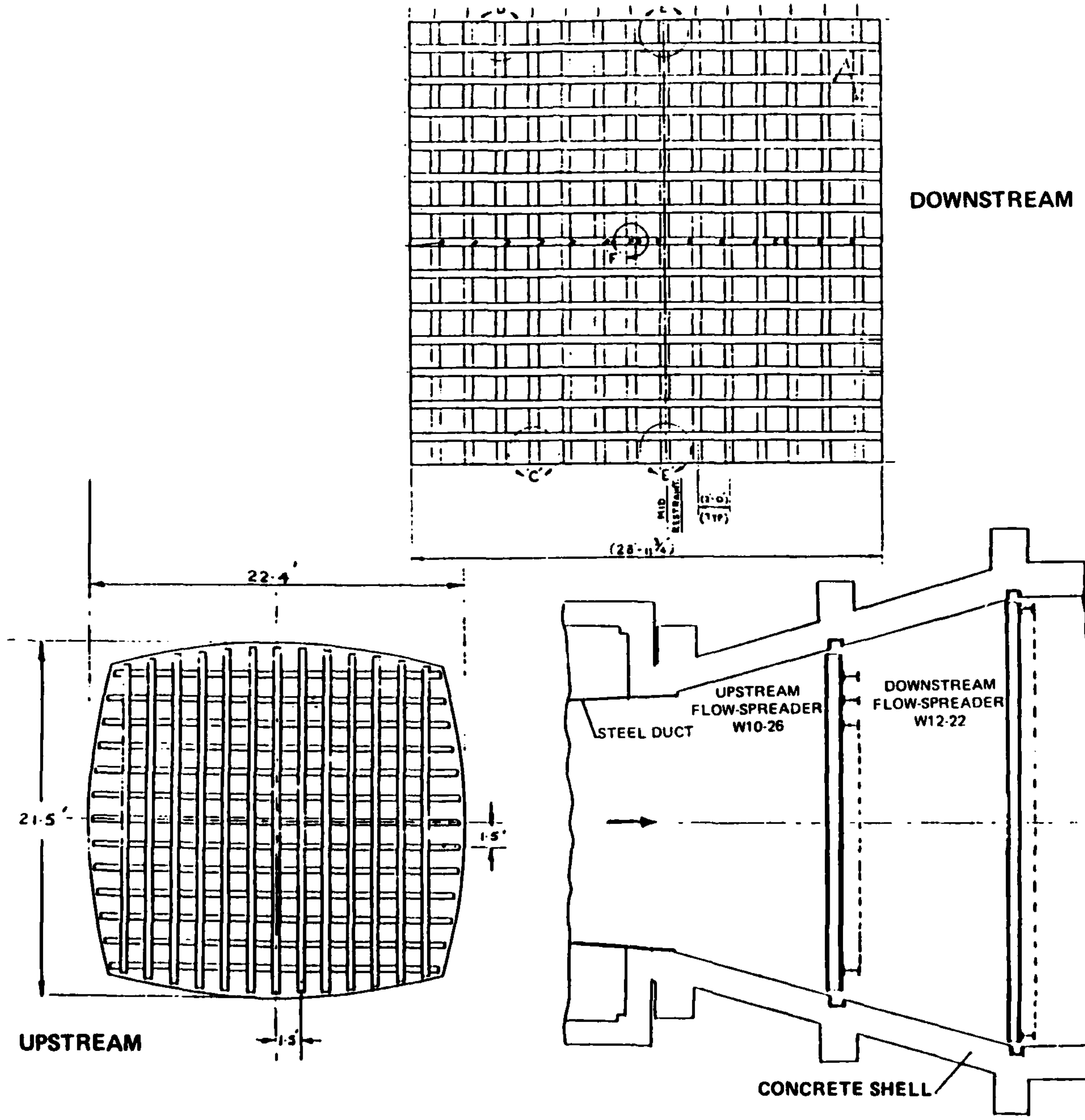


FIG. 11: EXIT DIFFUSER FLOW SPREADERS

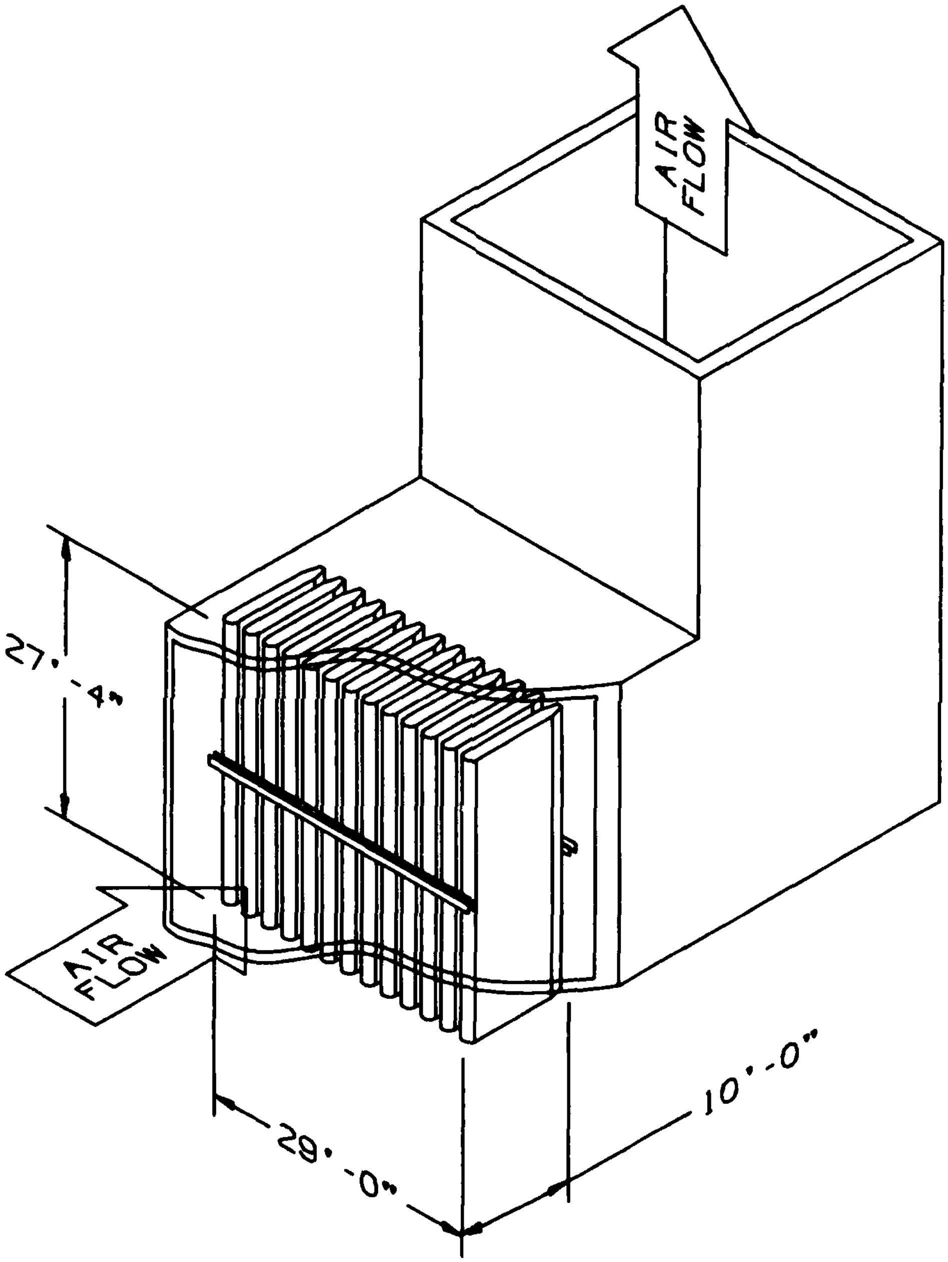


FIG. 12: EXIT SILENCER

FIG. 13: PITOT TUBE INSTALLATION AT UPSTREAM FLOW SPREADER

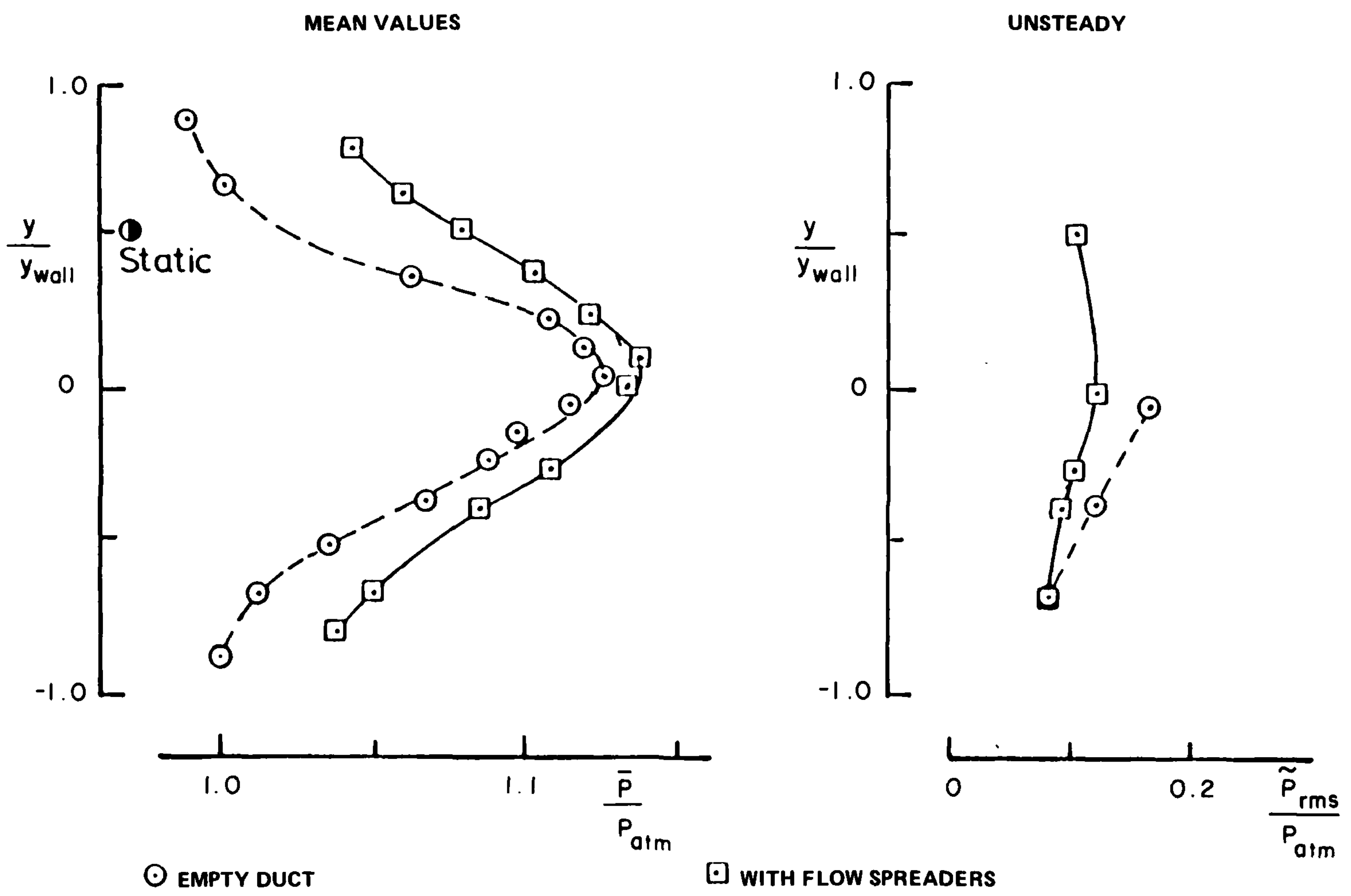


FIG. 14: COMPARISON OF STAGNATION PRESSURE DISTRIBUTION WITH AND WITHOUT FLOW SPREADERS

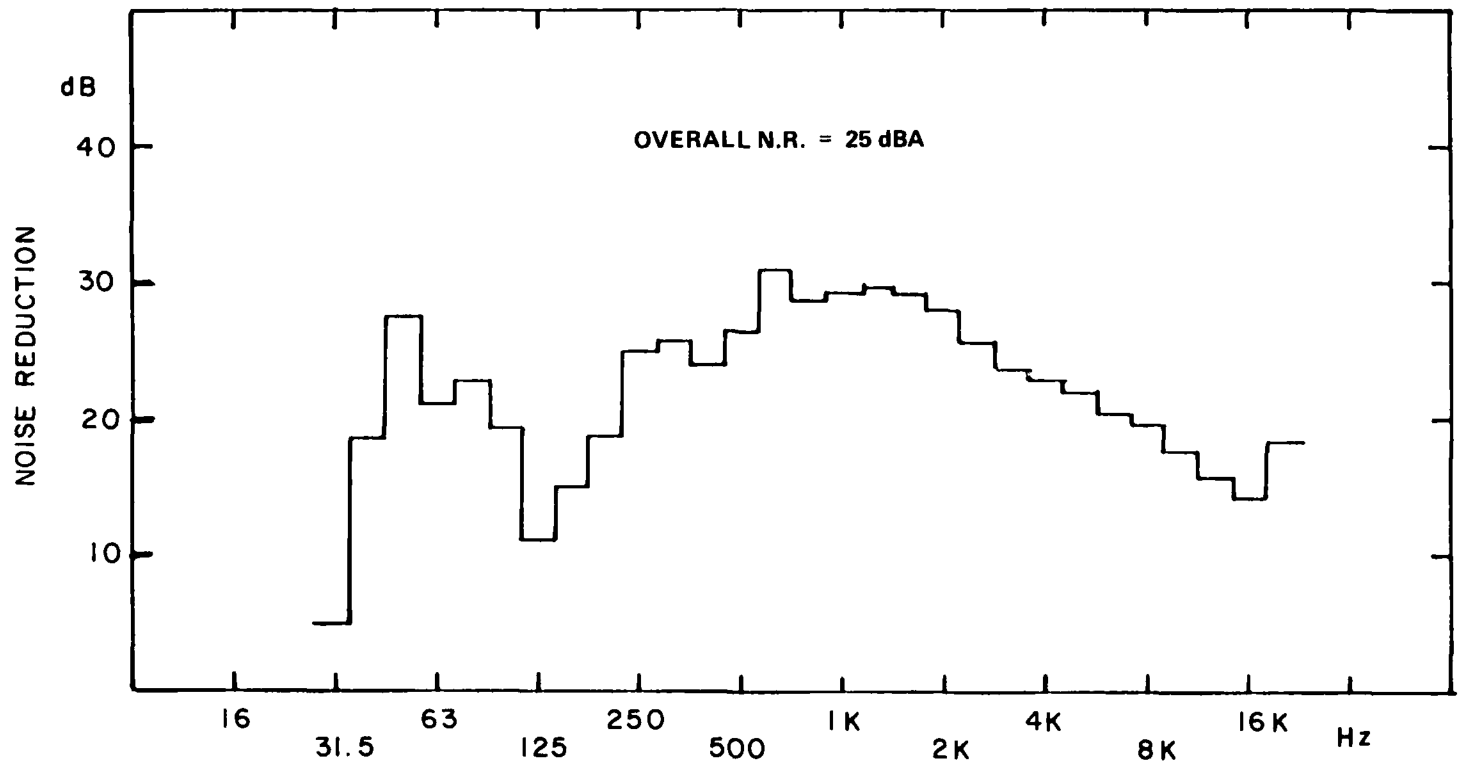


FIG. 15: EXHAUST SILENCER NOISE REDUCTION

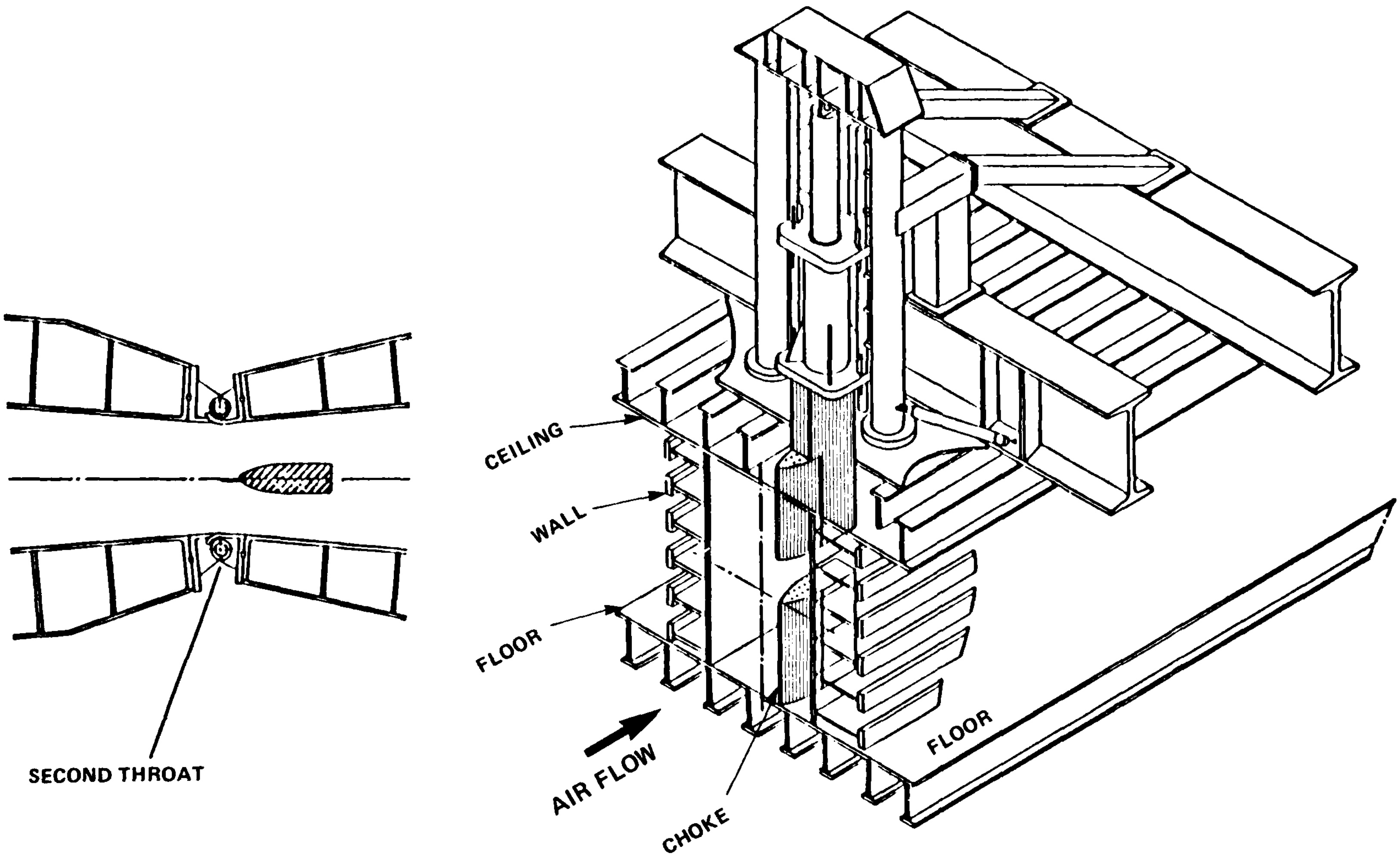


FIG. 16: CHOKE SYSTEM FOR MACH NUMBER CONTROL

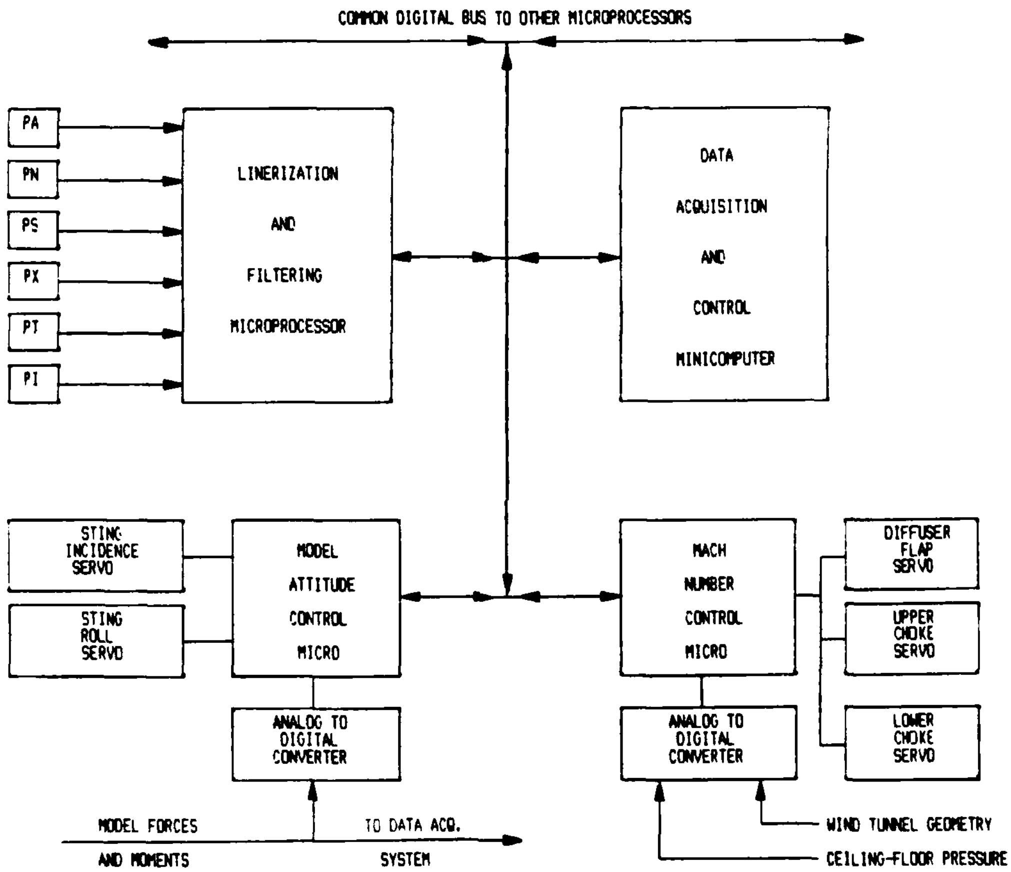


FIG. 17: MACH NUMBER CONTROL SYSTEM CIRCUIT

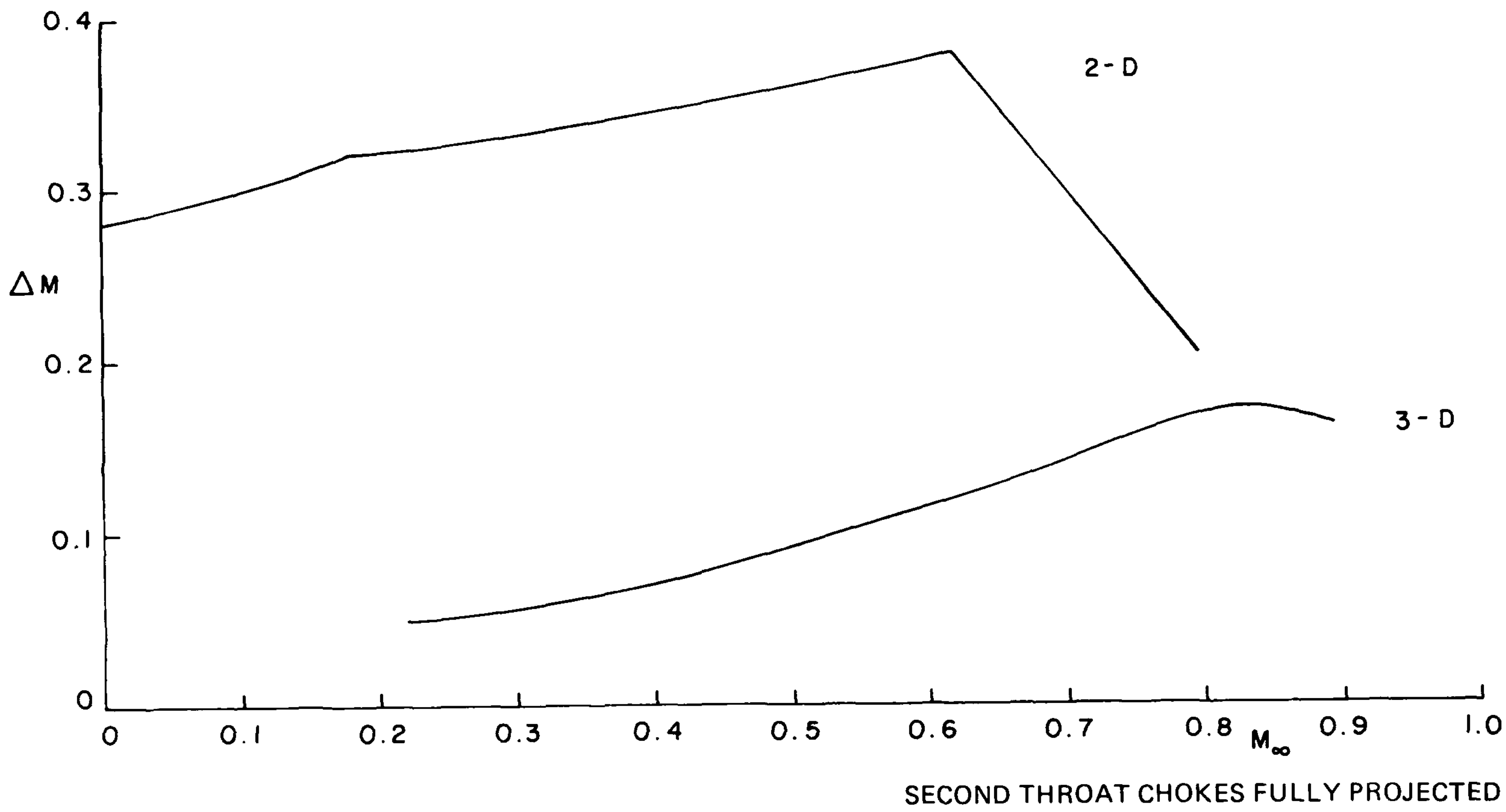


FIG. 18: PERFORMANCE OF CHOKE CONTROL SYSTEM

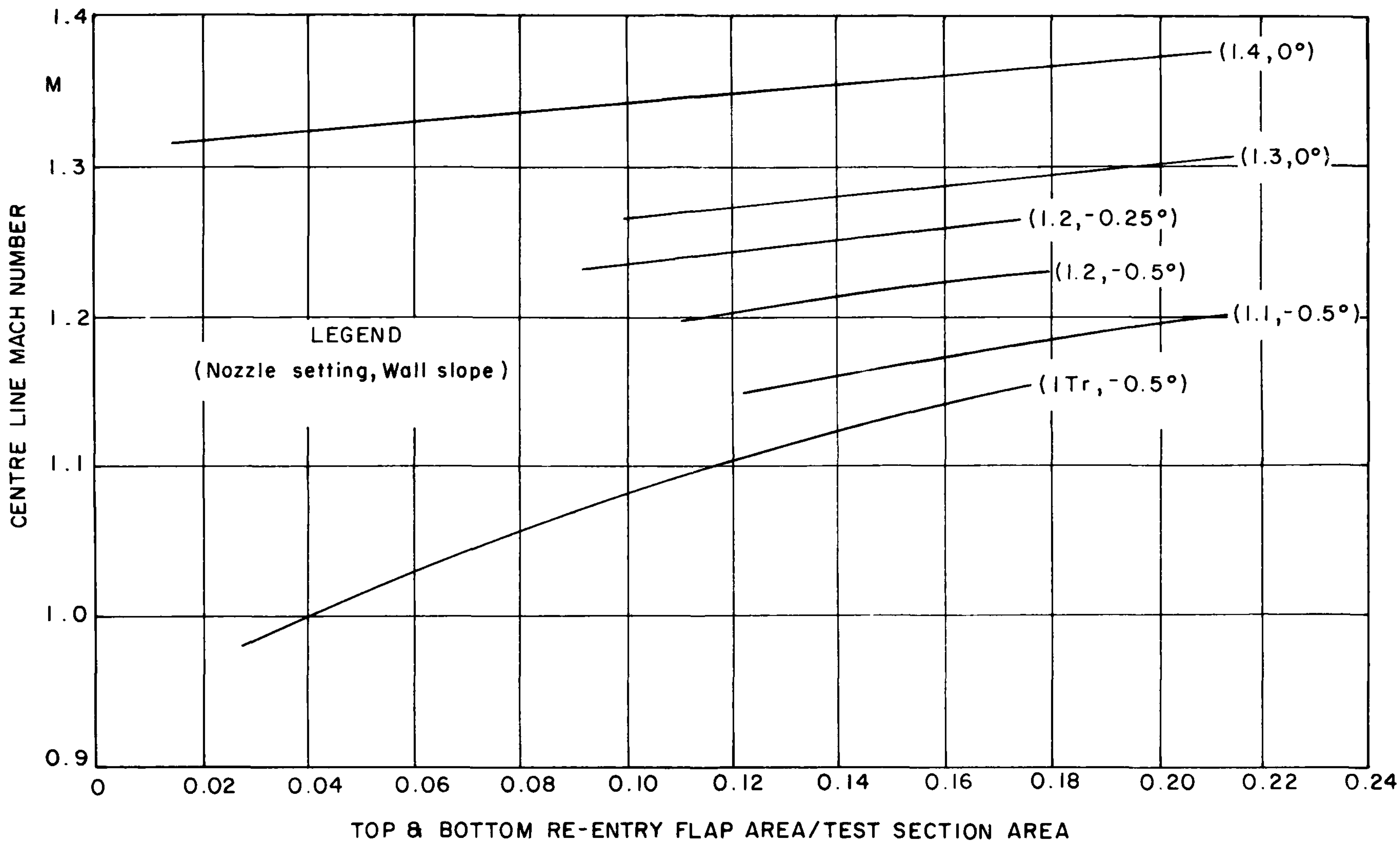


FIG. 19: PERFORMANCE OF RE-ENTRY FLAP CONTROL SYSTEM

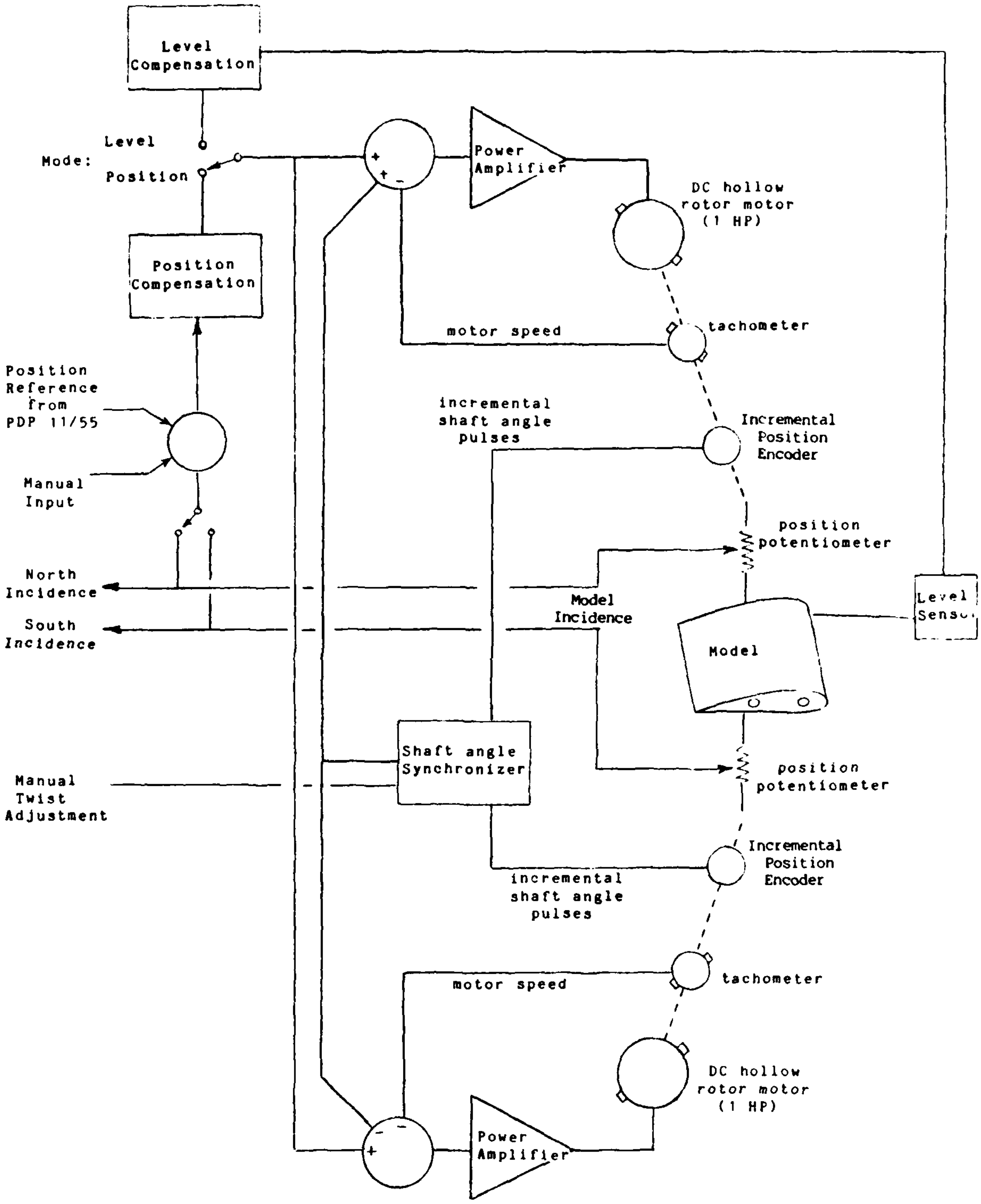
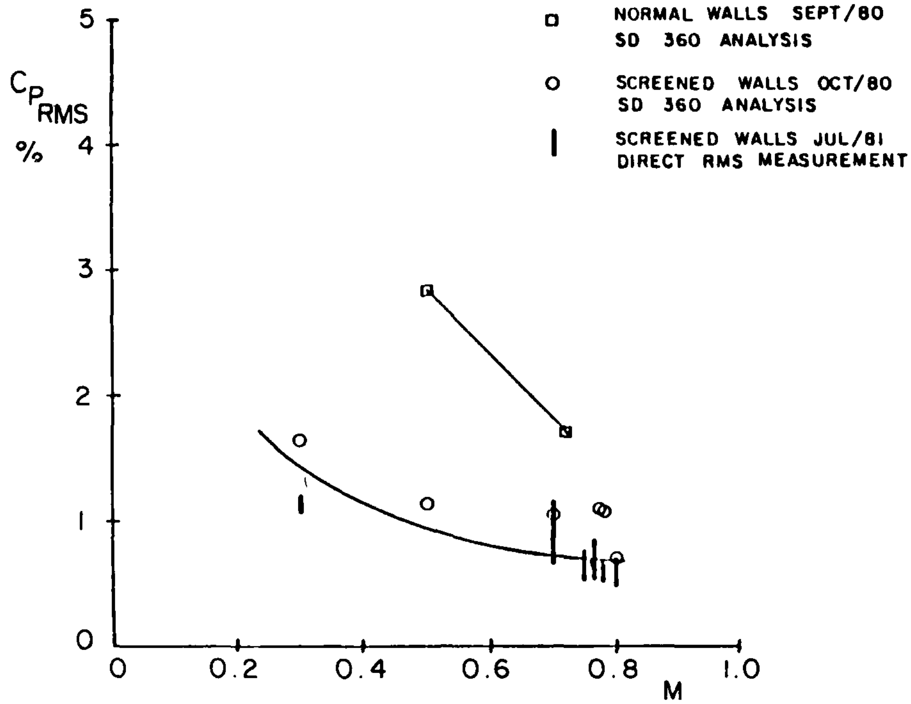
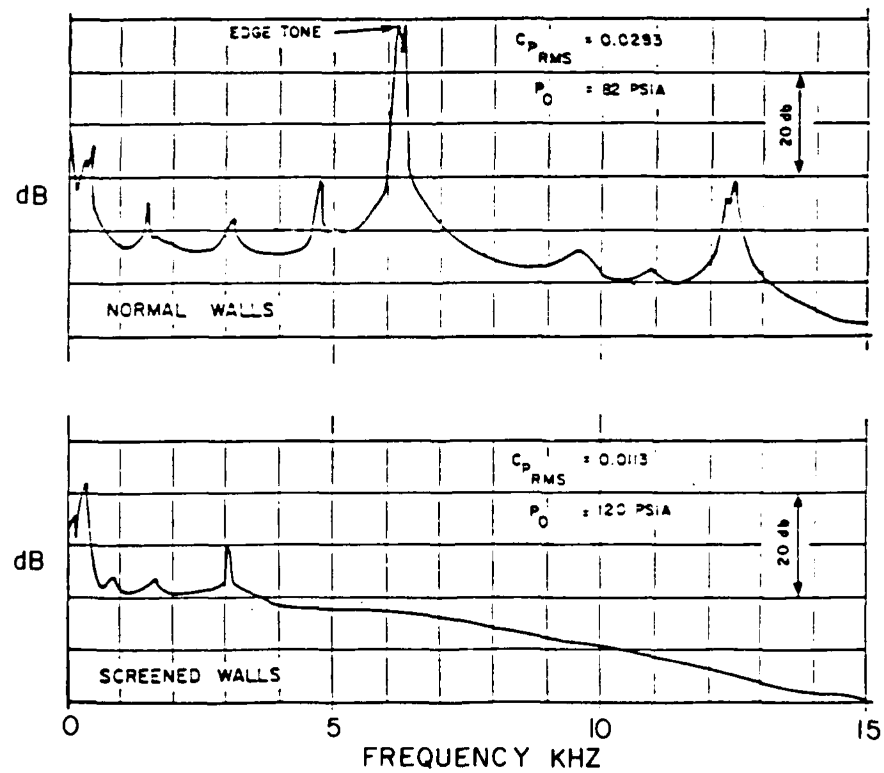


FIG. 20: 2-D BALANCE DUAL DRIVE SYSTEM



OVERALL NOISE LEVEL



TYPICAL POWER SPECTRAL DENSITIES M_∞ = 0.5

FIG. 21: 2-D TEST SECTION OVERALL NOISE LEVEL

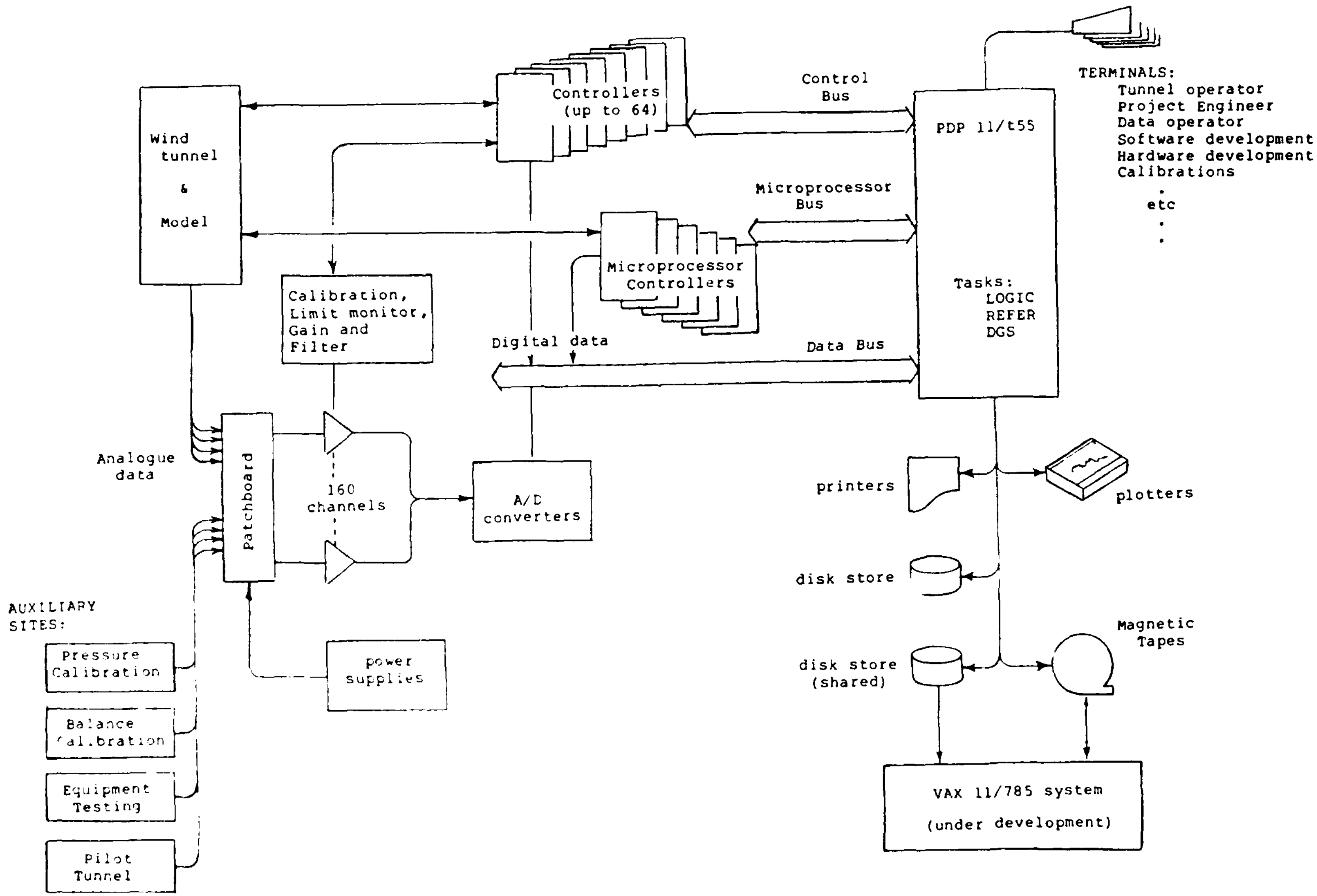


FIG. 22: NAE 5 FT × 5 FT WIND TUNNEL CONTROL AND DATA PROCESSING SYSTEM

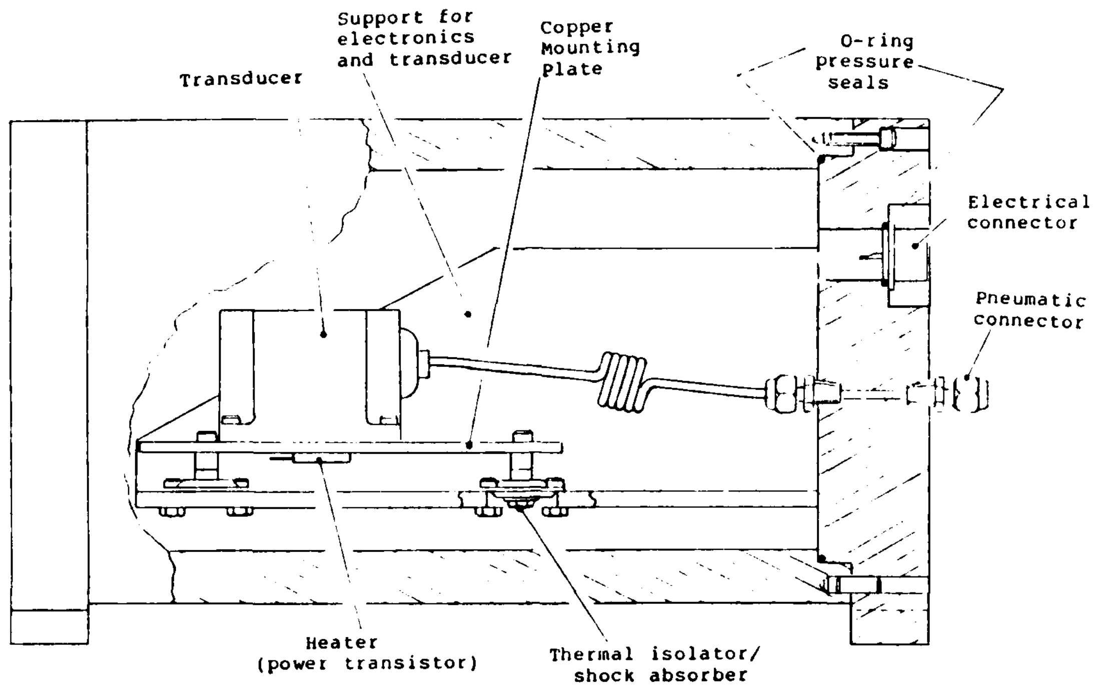


FIG. 23: INSTALLATION OF DIGITAL QUARTZ CRYSTAL TRANSDUCER

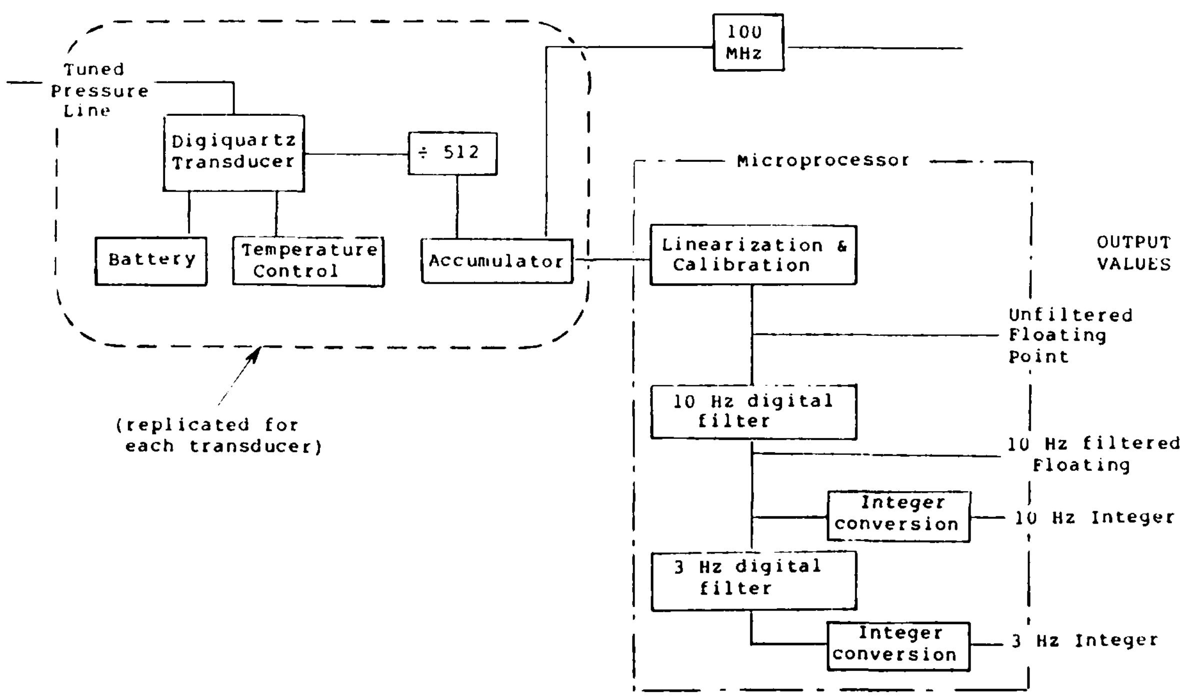


FIG. 24: SCHEMATIC OF DIGITAL TRANSDUCER CIRCUIT

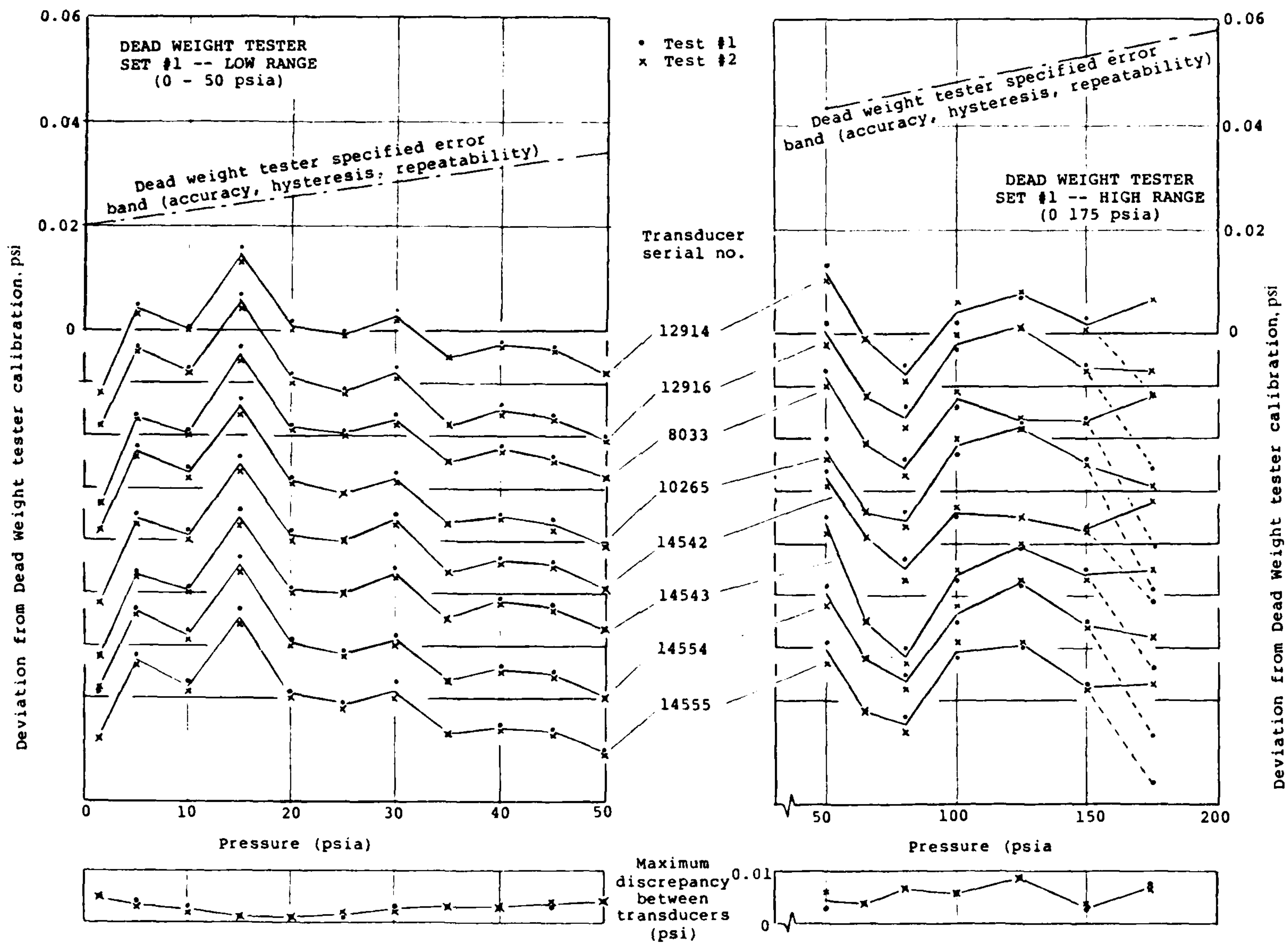


FIG. 25: TYPICAL TRANSDUCER CALIBRATION DATA

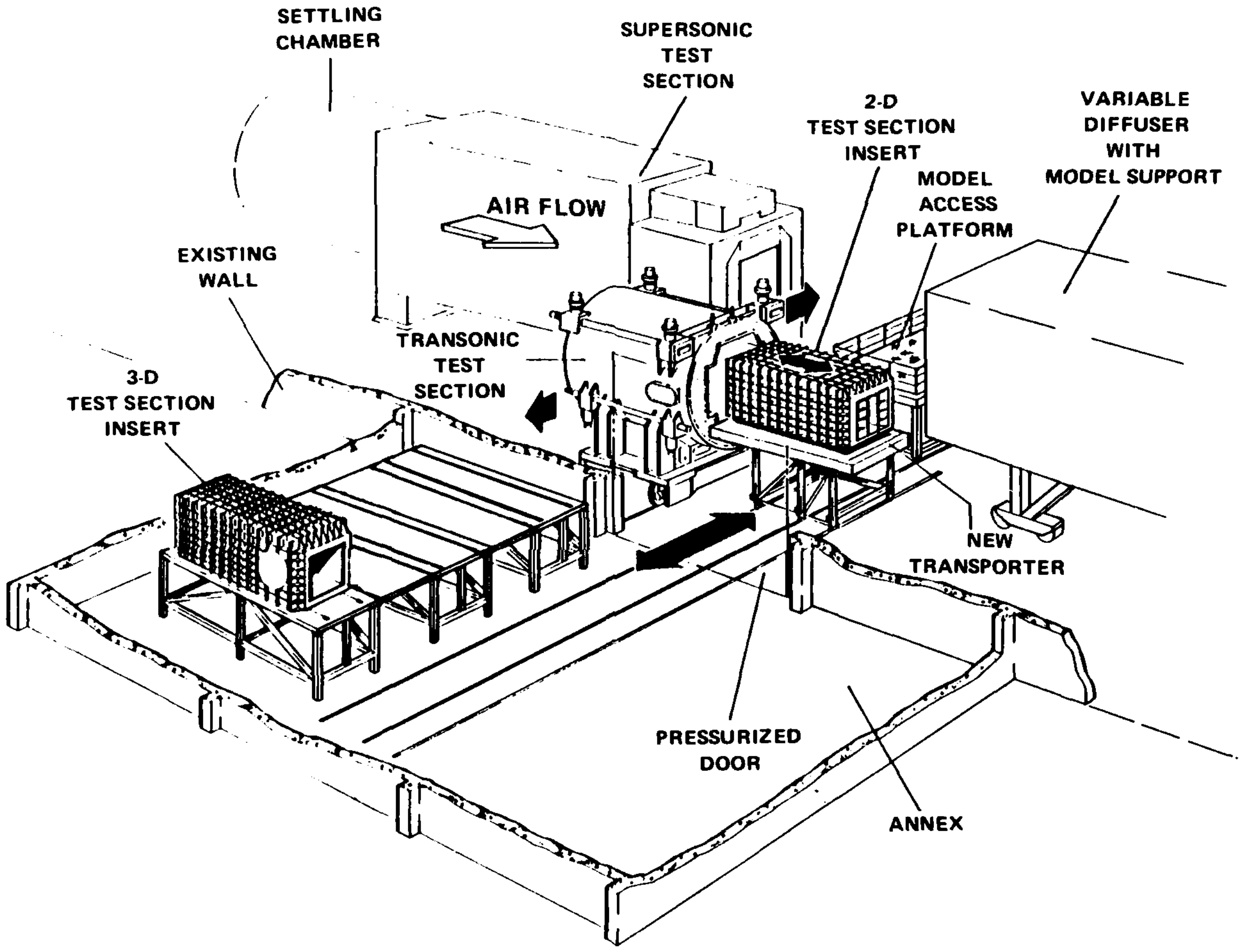


FIG. 26: ROLL-IN ROLL-OUT TEST SECTION, NAE 5 FT × 5 FT WIND TUNNEL

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Recent Improvements to the NAE 5 Ft X 5 Ft Blowdown Wind Tunnel

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AUTHOR(S)/AUTEUR(S)

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SERIES/SÉRIE

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NOTES

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DESCRIPTORS (KEY WORDS)/MOTS-CLÉS

1. Wind tunnels (NAE 5 ft X 5 ft)
2. Wind tunnels (blowdown)
3. Wind tunnels (subsonic)
4. Wind tunnels (transonic)

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SUMMARY/SOMMAIRE

Although the NAE 5 ft X 5 ft Blowdown Wind Tunnel was conceived in the 1950's, with commissioning in 1962/63, it has stood the test of time very well and is still, in 1985, in heavy demand. We may cite three main reasons for this situation: (i) the basic wind tunnel design was fundamentally very sound, (ii) the wind tunnel circuit and its auxiliary systems have frequently been improved and modernized so that it, even today, is a modern up-to-date facility, (iii) the high level of competence of the supporting staff. In this report we present the major improvements made in recent years and the impact these have had on the performance of the facility.

The improvements elaborated on are: The rebuild of the settling chamber; The rebuild of the exhaust diffuser; The installation of active Mach number control for subsonic-transonic operation; The incorporation of dual drive on the two-dimensional insert balance system; The suppression of edgetone noise; The incorporation of highly accurate digital pressure transducers; The control and data processing system.

Finally, future plans for expanded utilization of the wind tunnel are outlined.

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